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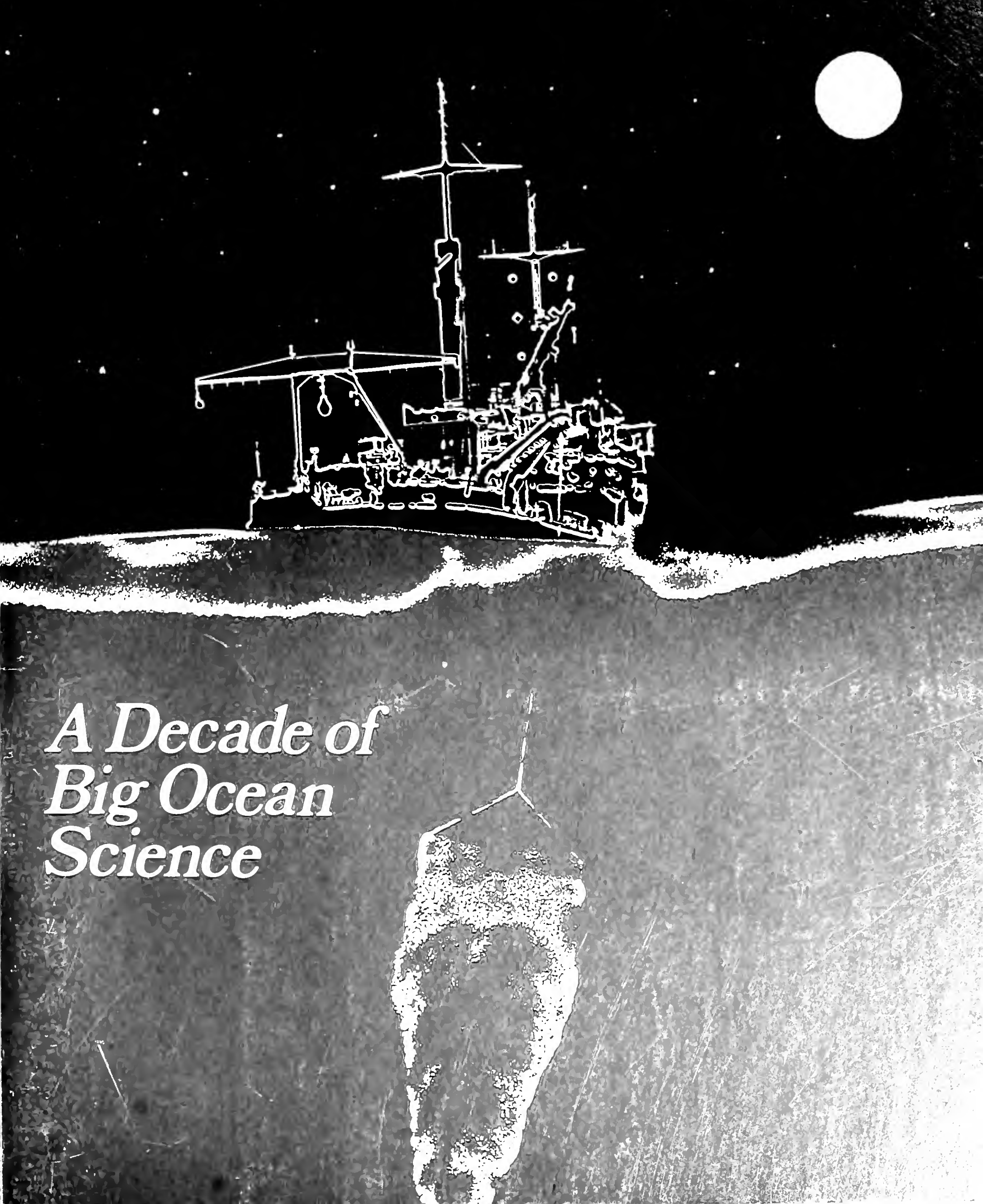

A Decade of Big Ocean Science

Oceanus®

The International Magazine of Marine Science

Volume 23, Number 1, Spring 1980

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Contents

FRONT COVER: The R/V Atlantis II *conducting a mid-water trawl (MOC-10). Photo rendering by Anita Brosius © 1980: BACK COVER: International Decade of Ocean Exploration logos and patches.*

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Genesis of a Marine Policy – The IDOE*

*Condensed from Chapter 5 of *The Politics of the Ocean*, by the author, copyright 1972 University of Washington Press.

Atlantis II *on IDOE cruise in 1973.*

by Edward Wenk, Jr.

One of the most significant events in recent maritime history was the inauguration 13 years ago of the International Decade of Ocean Exploration (IDOE). Its genesis not only exposed critical intersections of science and politics, but it also represented one of the rare occasions when a President (Johnson — 1968) chose a State of the Union message to establish a connection between our national interests and the ocean. Three different activities had to be synthesized for effective policy design: presidential decisions to meet geopolitical opportunities; the establishment of new goals for faltering marine research; and the setting up of large-scale marine affairs machinery for planning and coordination. What follows is an account of what happened — how and why — with special attention to the often neglected political stage on which the actors projected their individual ideas.

The Legislative Setting

On June 17, 1966, President Johnson signed Public Law 89-454 into effect — establishing for the first time a legislative mandate for systematic exploration and use of the sea. The congressional initiative for this action was triggered by the 1957 Soviet space surprise that jolted the nation and the entire scientific establishment — the launching on October 4 of Sputnik 1, the world's first Earth-orbiting unmanned satellite — and later by the 1959 report by the National Academy of Sciences (NAS) that documented the flaccid state of marine affairs.

Congress initially took up the cudgel of maritime advocacy to match the unknowns of Soviet capability. President Kennedy met that concern with a massive budgetary transfusion in 1961. But then congressional criticism shifted to unwitting duplication and lack of coherence in federal efforts as a result of their dispersal among 23 agencies. No longer confident that bureaucratic factions were coordinated through a subcabinet-level Federal Council for Science and Technology, Congress in 1964 sought to stem the drift in momentum and council leadership with new and far more potent legislative medicine.

The Marine Sciences Act of 1966 culminated that seven-year period which began with the NAS report. A forceful policy was asserted to turn the seas to the benefit of humankind. And the President was explicitly designated bandmaster, to assure that the orchestra not only played better, but also played the same tune. To advise and assist the President, the Act created a policy-planning Marine Council at cabinet level, chaired by the Vice President, with a full-time staff appointed by the President. Finally, a commission was established to study government reorganization.

With the medium as the message, the Marine Council gave unprecedented symbolic visibility to ocean affairs. As a maritime presence in the White House, it partly compensated for the clumsy, fragmented, and ineffective lobbying for ocean policy. The still fledgling instrument was to play the key role in the generation of the IDOE concept in the fall of 1966, and in its stewardship through adoption by both the Johnson and Nixon administrations. Ironically, the Council was disestablished in 1971 on the misguided belief by the newly created National Oceanic and Atmospheric Administration (NOAA) that it could provide the same presidential staffing and government-wide leadership as the Council. It is somewhat ironic today to hear enthusiastic advocacy for re-establishment of the Council apparatus based on the widespread perception that marine affairs again lack both the proper support and direction at the highest levels.

Foreign Policy Instructions

Whereas the marine affairs legislation set forth a portfolio of general domestic goals, it was more explicit in its foreign policy instructions. The President in concert with the Council was to advance marine initiatives that would contribute to cooperation with other nations and international organizations. It also mandated that studies of the Law of the Sea be initiated with a view toward updating 1958 conventions to meet the effects of a rapidly changing technology. In a July 13, 1966, address, commissioning the research ship *Oceanographer,* President Johnson switched on the Marine Council, then stressed the need for cooperation in the foreign policy arena: "Truly great accomplishments in oceanography will require cooperation of all the maritime nations . . . I am calling for such cooperation, requesting it, urging it . . ." At the same time, he laid down guidelines to head off colonialization of the seabed. That philosophy, incidentally, went well beyond an abstraction of scientific interchange. It was driven by a quest for a stable, lasting peace, despite the paradox of a growing commitment to Vietnam.

The U.N. Geopolitical Setting

The grind of Cold War competition with the Soviet Union influenced the geopolitical perspective for marine policy planning. The United Nations was still thought of as a theater for easing tensions because of its neutral multilateral cover for collaboration. Progress had been made in space affairs through a new committee of the General Assembly, and in ocean research through the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific, and Cultural Organization (UNESCO).

Growing interest in opportunities afforded by the sea for Third World development also came about with the passage of a United Nations Economic and Social Council (ECOSOC) resolution, 1112 (XL), of March 7, 1966, calling for a worldwide survey of marine resources; followed by a General Assembly resolution, 2172 (XXI), of December 6, 1966, specifying an inventory of national oceanographic capabilities. But it was Ambassador Arvid Pardo of Malta, on August 18, 1967, who enlivened the 22nd session of the General Assembly with a proposition to internationalize the seabed beyond narrow territorial limits, holding out the promise of quick wealth — to be shared by all — from exploitation of seabed minerals. Coming at a time when Third World independence was the subject of heated political rhetoric, Pardo's proposition advanced interest in both accelerating exploration and in establishing a clearer framework of law regarding the stake coastal nations had in prospective maritime development.

President Johnson at commissioning ceremonies for the research vessel Oceanographer *in 1966. He stated that great accomplishments in oceanography would require the cooperation of all maritime nations. (Wide World Photo)*

Such stimuli as Pardo provided often goad ponderous bureaucracy to action. But not in this case. Four bureaus within the State Department had jurisdiction over ocean affairs. All responded with conservative, defensive proposals. The major response to Pardo's proposition was to be generated by the Marine Council, based on foreign policy initiatives it began at its creation.

The Scientific Connection

The Marine Council regarded the course set by both the President and Congress toward multi-national enterprise as *sine qua non* to initiatives it was undertaking, including those to strengthen the domestic scientific base. Although both branches of government had ungrudgingly pumped funds into research in response to the Soviet space surprise, by 1966 funding had leveled off. Indeed, the Johnson Administration was reluctant to fund basic research with carte blanche, annual 15 percent increases, such as advocated by leading scientists. Oceanographers noticeably winced at the funding squeeze. Oceanography was a late starter in competing for funds, and, during its transition from a "little" to a "big" science, costs rose swiftly; new ships and labs required greater operating funds. Also, oceanography lacked prestige within the scientific community.

However, it was recognized that the oceanographic community represented a major capability for ocean exploration, equal in certain respects to the federal government's own resources. It had a long tradition of global exchange and cooperative exploration. From the outset, it was appreciated that IDOE success critically depended on support of the oceanographic community. This community was not, however, to be a willing partner.

First, many scientists resented the fact that oceanography was funded almost 100 percent by the government. They also were wary of project control by sponsors and of promises by political leaders that sometimes were slowly honored. This love-hate relationship was manifested in a variety of ways. One was avoidance by scientists of programs clearly intended to contribute to foreign policy goals, while tickling more funds through other scientific projects under an international rubric from a government eager to use the neutrality of nongovernmental linkages.

During the Johnson Administration, amid tighter budgets and a growing hostility toward academic science because of Vietnam, any proposal to support science would have been rejected during the budget process. That constraint was never fully appreciated by the scientific community. Neither was the need to guard the IDOE concept during its

Ambassador Arvid Pardo of Malta stating that the ocean floor should be reserved for peaceful purposes. His statement came before a committee at the United Nations in 1967. (Photo courtesy United Nations)

gestation, because President Johnson had such a penchant for surprise in announcing new initiatives that any leak during project development spelled its doom. But even when the scientific community saw the benefits to research resulting from the IDOE initiative, they resented not being involved and having full control from the outset. Nevertheless, after the State of the Union address, both the National Academy of Sciences and the National Academy of Engineering (NAE) were invited (and funded) to develop independent technical proposals.

The Marine Council secretariat thus was faced with conflicting challenges that never evaporated— how to harmonize the needs of science with domestic policy and foreign policy objectives. The domestic objectives involved using the sea to meet social needs, whereas foreign policy objectives were geared toward fostering new patterns of intergovernmental collaboration because the ocean was still seen as offering opportunities for new steps toward world order.

The IDOE Concept

The IDOE concept was generated to contribute to the previously mentioned goals. It envisioned a systematic program of ocean exploration motivated by anticipated uses of marine resources as much as by scientific curiosity, with expansion in exploration capabilities by many nations. It was hoped that an enhanced base of facts, a common understanding of marine resource potential, and more experience in collaboration could set the stage for an enlightened advance in Law of the Sea negotiations. Perhaps more rational steps could be taken to clarify the rights of developers of the sea, to preserve the seas' traditional freedoms, and to lend credibility to the notion of "a common heritage of mankind," assuring more equitable economic benefits to all participants. Substantive objectives emphasized development of knowledge to manage resource development and conservation, to preserve the quality of the ocean environment, to improve forecasts of sea state and weather, and to inventory fishery, seabed, mineral, and energy resources.

The IDOE enterprise was thus not to be a continuation or simple expansion of past research efforts. Moreover, exploration of the seas was to be sustained rather than episodic; planned as a global effort rather than as a patchwork of national programs, or more usually, as a loose collection of projects by individual scientists. It would involve a network of international marine organizations so as to integrate *users* as well as *producers* of scientific knowledge. It also was designed to help nations with modest research capabilities, so that such countries would not be inadvertent captives of the technologically advanced participants. And the enterprise was to incorporate government-to-government as much as scientist-to-scientist collaboration.

In retrospect, these goals seem too ambitious, especially given implementation complexities, budgetary stress resulting from the Vietnam war, hesitant support from government agencies, and antagonism from the scientific community. But then, that era was characterized by the boldness in leadership of the brilliant, feisty, and respected Marine Council Chairman, Vice President Hubert H. Humphrey.

Whatever the virtues of the IDOE concept, support first had to be obtained from the President. Support also was needed from Congress, participating federal agencies, the scientific community, industrial marine enterprises, other nations, the United Nations, and interscientific bodies. There was great diversity among these in roles, history, lifestyles, parochial self-interest, and institutional conflicts. These last had long existed between the White House and the State Department, between the government and the scientific community, between international units jockeying for position, and between the United States and other nations. But the conflict that was feared the most in the shadow of Cold War politics was between the United States and the Soviet Union; it never materialized.

Nevertheless, the Marine Council secretariat was obliged to invest prodigious energies in trying to move all the potential players toward a

Nations participating in IDOE as of October, 1978: Argentina, Australia, Belgium, Canada, Chile, Colombia, Denmark, Ecuador, Finland, France, East Germany, West Germany, India, Indonesia, Israel, Italy, Japan, South Korea, Malaysia, Mexico, Morocco, The Netherlands, New Zealand, Norway, Mauritania, Peru, Philippines, Portugal, Singapore, South Africa, Spain, Thailand, Britain, United States, the Soviet Union, and Venezuela (shaded areas).

consensus. A five-pronged planning strategy evolved: 1) to characterize economic, social, political, and scientific goals that would be enhanced by multi-national ocean exploration; 2) to estimate technical capabilities and funds required; 3) to examine mechanisms of expedition planning and deployment that would afford a felicitous blend of in- and out-of-house expertise; 4) to identify steps to gain approval or cooperation at the level of the President and of other nations; and 5) to evaluate the needs for and strengths of the international apparatus. These tasks entailed efforts by the Marine Council and its secretariat, as well as by a high-level interagency committee reporting to the Vice President, a panel of special consultants from science and industry, and by contract studies.

Marine Council International Initiatives

Under the 1966 legislation, the Marine Council was required to prepare an annual report for the President and Congress. These reports set forth both the status of government-wide activities and a prospectus for new actions that would advance and strengthen the total effort. Toward that end, President Johnson directed the Council to deliver its first annual report at the end of its first six months of operation. Obliged to work feverishly, the Council secretariat generated a series of initiatives. By December, 1966, nine such topics were approved. The foremost was "international activities," the precursor of the International Decade of Ocean Exploration.

These marine policy initiatives gained widespread exposure in March, 1967, when the President released his first annual report. Soon after, an unexpected opportunity arose to test foreign response when President Johnson asked Vice President Humphrey to explain the growing U.S. involvement in Vietnam to our European allies. Humphrey brought the Marine Council's staff director along to explain the new U.S. focus on ocean policy. Policy discussions at high levels were conducted in Britain, France, Italy, West Germany, the Netherlands, and Belgium. Intergovernmental communication was opened, and all the nations were encouraged to integrate their own internally fragmented marine activities and to raise ocean-related priorities. Moreover, Humphrey sought to ease anxieties among our allies by explaining that the new ocean initiatives were not being taken for military advantage.

The Internal Policy Process

The primary track for generating an IDOE proposal to the President lay within the Marine Council process, with review and endorsement by cabinet officers. The State Department was encouraged, by virtue of its traditional mission, to take intramural leadership of the still ungelled program, but that agency, lacking imagination as to potential new policy lines, saw IDOE only as a ploy to delay action at the United Nations. Moreover, State wanted to exclude fisheries from IDOE's scope since it had long engaged in multi- and bi-lateral fishery policy decisions without coaching from the White House. Although the Marine Council was unwilling to settle for State's cautious stance, the fate of the IDOE concept in the summer of 1967 was uncertain. State continued its resistance; an interagency planning group urged delay, reporting that at least six months was needed to develop a substantive framework to back up the concept; and individual agencies,

under budget constraints, became nervous because they felt the IDOE might cut into their old favorites.

Fortuitously, a second channel to President Johnson opened up. Joseph Califano, then Special Assistant to the President, tried to inject new vitality into lagging government programs, and a creaky, cranky bureaucracy. He did this by soliciting nominations for presidential initiatives from a select group of individuals in and out of government. The dragnet was given added spice by an "eyes only" security classification. In May, 1967, the Council's *executive secretary* (the author, but ironically not its *chairman*, Vice President Humphrey) was invited to participate. By August, the International Decade of Ocean Exploration had survived strong attempts to bury the initiative and was among the finalists that then underwent further refinement, still with utmost secrecy. Califano thus sent IDOE among his nominations to the President.

On December 11, Vice President Humphrey, as Marine Council Chairman, transmitted his recommendations to the President, noting unanimous support of the IDOE project and arguing the case in terms of food for expanding world population, maritime threats to world order, waterfront deterioration in coastal cities, increased pollution at the shoreline, expanding requirements for seabed oil, gas, and minerals, and expanded ocean shipping.

President Johnson delivering State of the Union message on Jan. 17, 1968. He announced a proposal to "launch with other nations an exploration of the ocean depths to tap its wealth and its energy and its abundance." Behind him is Vice President Humphrey, then Chairman of the Marine Council. (Wide World Photo)

President Johnson's Backing

In his State of the Union message on January 17, 1968, President Johnson stated that "this year, I shall propose that we launch with other nations an exploration of the ocean depths to tap its wealth and its energy and its abundance."

Details were added in the annual report: the President said ". . . we invite and encourage (other nations') interest. . . For our part, we will . . . reaffirm the traditional freedom of the seas . . . encourage mutual restraint so that the oceans do not become the basis for military conflict . . . seek international arrangements to insure that ocean resources are harvested in an equitable manner."

Still further elaboration developed in the President's Conservation Message of March 8 when he explicitly blessed the enterprise with the appellation "International Decade of Ocean Exploration for the 1970s."

The next step was the development of a White Paper in which all parties identified their interests and developed proposals for the next steps of implementation. Even that modest enterprise proved difficult. It soon was realized how limited and inept planning by scientists had been for prior expeditions, and how strong were the interagency rivalries and how debilitating was the often self-serving ambivalence of the scientific community.

International Response

As the domestic participants of IDOE were prodded to overcome their timidity and to engage in a new opportunity, the Marine Council secretariat began to seek international cooperation in earnest. The most essential partner was the Soviet Union. Its oceanographic capabilities approximately matched ours; together we accounted for 70 percent of the global research capacity. A dialogue was begun with the Soviet representatives at the United Nations, followed by a visit by the Marine Council's executive secretary (the author) in June, 1968, to Moscow. Conversations were undertaken with senior officials in the Foreign Ministry, the State Committee for Science and Technology, the Ministries of Fisheries and Hydro-Meteorological Services, and the Soviet Academy of Sciences. Questions concerned funding levels and which existing United Nations agencies might serve to aid in planning the steps for necessary cooperation and serve as a sanitary tent for a U.S./Soviet rapprochement. Discussions were cordial and candid; the United States' team urged their Soviet counterparts to join in all international forums — such as the Intergovernmental Oceanographic Commission, the U.N. Seabed Committee, and the Special Committee on Oceanic Research.

Meanwhile, in a campaign to solicit more IDOE support, the Marine Council secretary visited Britain, Norway, West Germany, France, Italy, South Korea, Japan, Brazil, Venezuela, Mexico, and Canada. In all conversations, these nations were initially ambivalent because of low marine priorities

and problems of internal coordination; before making commitments they wanted assurances that others would play; and each was apprehensive about another nation gaining political advantage. Not only was this a chicken-egg dilemma; it meant dealing with an entire hatchery. But support gradually emerged.

On June 13, 1968, a formal recommendation of support for the IDOE was adopted by the Intergovernmental Oceanographic Commission. The Marine Council secretariat later sought support in all other available international forums — ECOSOC, the World Meteorological Organization, the Commission for Maritime Meteorology, the United Nations' Food and Agriculture Organization, the U.N.'s Seabed Committee, and finally, in the General Assembly itself. Support was obtained in proposition three of General Assembly Resolution 2467 (XXIII), co-sponsored by 28 nations.

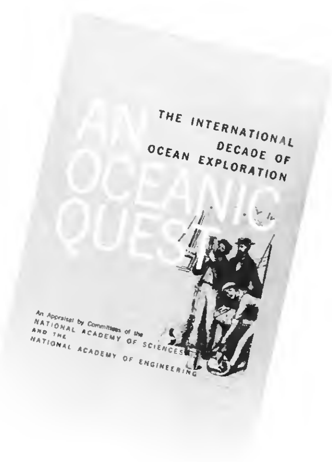
Conflicts Between Government and Science

The Marine Council secretariat soon discovered that domestic support would be as difficult to attract as foreign. The first question was whether the scientific community would support the IDOE proposal under the presidential imprimatur. Indeed, it failed to prove alluring. Immediately after the President's announcement, the secretariat sought advice from the National Academy of Sciences' Committee on Oceanography (NASCO), the National Security Industrial Association, and the Marine Technology Society. But leaders in oceanography, even those who wore other hats as Marine Council consultants and had supported the concept as it was being generated, started to snipe at the initiative.

For one thing, there was suspicion that the flag- and arm-waving of the IDOE announcement was possibly a political maneuver by a President who was hostile to science and unlikely to follow through with funding. Moreover, scientists were worried about the possibility of political involvement by the United Nations through the Ad Hoc Committee to Study Peaceful Uses of the Seabed and the Ocean Floor Beyond Limits of National Jurisdiction, which was seen as a threat to the IOC (controlled by the scientific community). At that time, few marine scientists understood the legislative mandate as relating the seas to human concerns. Indeed, many were satisfied to study the oceans as though the planet were uninhabited. And few understood the budgetary obstacle course or the need to join forces with the secretariat to continue momentum.

So the nervous gavotte between government and science never resulted in being totally in step; they could not live apart, but their symbiosis never was fully appreciated either so they could live together. The key issue was control of funds. The Marine Council always anticipated a partnership between the scientific community and the government in which scientific objectives would be melded with practical goals. This meant that a unified staff of insiders and outsiders, scientists and engineers, needed to work together in planning the project. The problem was — who was in charge? Because of the legal responsibility for public funds and the necessity of coordinating federal agencies, the leadership for IDOE planning had to be vested unequivocally in a federal official. To encourage involvement by the scientific community, an offer was made to fill the spot with their nominee. It was rejected.

As an interim measure to keep the concept alive, a contract was signed in July, 1968, by the Marine Council with both the National Academies of Sciences and of Engineering to elicit their ideas in relation to the broad goals developed by the Council. Released in June, 1969, their joint report, entitled *An Oceanic Quest,* was an excellent job of



craftsmanship, in resonance with the IDOE concept and now mindful of such goals as economic development, management and conservation of resources, and reduction of ocean-based conflicts. Thus research goals of the 1959 National Academy of Sciences Committee on Oceanography report, couched in scientific terms and focused on disciplines, revealed a new maturity in understanding public policy toward uses of the sea. But the report also was unrealistic in its proposed funding level and in its expectation of simply giving funds to the scientific community for management of programs. Indeed, it carried the implicit admonition to provide enough new support so that no ongoing work funded by government would lose priority; and to let them run the entire show or they wouldn't play. To some in government, this seemed a genteel form of blackmail. Thus the impasse remained.

The Nixon Funding Decision

After the 1968 election, there was considerable uncertainty about continued political support for the IDOE. On the positive side, President Nixon responded to recommendations made by influential Republicans to retain the Marine Council staff, despite their appointment under a Democratic predecessor. However, the heated debates at the United Nations about seabed resources led a number of conservative congressmen to oppose the Council's international aims.

To be sure, in the January, 1969, marine science report of the outgoing President, IDOE was featured as top priority. But funding commitments were made only for planning, and the incoming administration was thought unlikely to back the project because it had an LBJ brand. The new administration, however, was persuaded by the Council's secretary to consider the unfinished business of its predecessor. But then ineptness on the part of the new Council Chairman, Vice President Spiro Agnew, almost spelled the death of the Marine Council and the IDOE project alike.

Unwilling to yield to the miasma of in-house uncertainty and faced with rejection by the scientific community, the Council secretariat stubbornly kept the IDOE concept alive by creating a special planning team within Council staff composed of specialists both inside and outside government. The team's assignment was greatly facilitated by the NAS/NAE report and especially planning inputs from two Council interagency committees. The team's recommendations were tested with outside consultants, the Stratton Commission examining permanent marine organizations, and with industrial groups. Then, on September 9, 1969, President Nixon made an unexpected request to the Council's secretariat for marine policy proposals. On October 19, five initiatives in marine affairs were announced by the new administration, the foremost being a commitment of $25 million in new money for IDOE.

In the January, 1970, report of the Marine Council, the following were listed as IDOE goals:

- *Preserve the ocean environment by accelerating scientific observations of the natural state of the ocean and its interactions with the coastal margin to provide a basis for (a) assessing and predicting man-induced and natural modifications of the character of the oceans; (b) identifying damaging or irreversible effects of waste disposal at sea; and (c) comprehending the interaction of various levels of marine life to permit steps to prevent depletion or extinction of valuable species as a result of man's activities;*

- *Improve environmental forecasting to help reduce hazards to life and property and permit more efficient use of marine resources – by improving physical and mathematical models of the ocean and atmosphere which will provide the basis for increased accuracy, timeliness, and geographic precision of environmental forecasts;*

- *Expand seabed assessment activities to permit better management – domestically and internationally – of marine mineral exploration and exploitation by acquiring needed knowledge of seabed topography, structure, physical and dynamic properties, and resource potential, and to assist industry in planning more detailed investigations;*

- *Develop an ocean monitoring system to facilitate prediction of oceanographic and atmospheric conditions – through design and deployment of oceanographic data buoys and other remote sensing platforms;*

- *Improve worldwide data exchange through modernizing and standardizing national and international marine data collection processing, and distribution; and*

- *Accelerate Decade planning to increase opportunities for international sharing of responsibilities and costs for ocean exploration, and to assure better use of limited exploration capabilities.*

This U.S. contribution to an expanded program of intergovernmental cooperation reflects four recent developments:

(1) Increased population concentration along the coasts of the United States and other countries, with attendant threats of harmful degradation of the ocean environment, and increasing demands on the coastal margins and marine resources.

(2) Evolution of technology that is rapidly opening new ocean frontiers.

(3) Recent scientific advances that can improve environmental forecasts if better ocean data are available.

(4) Sharply increasing interests by 100 coastal nations in extracting benefits from marine activities.

The Decade will accelerate needed understanding of the ocean – permitting nations individually to plan investments and collectively to develop arrangements for preserving the ocean environment and managing common ocean resources.

The global character of the oceans and the scope of work to be done make international cost-sharing and data exchange especially attractive. International cooperation in marine affairs is expected to facilitate communication with developing nations, with the Soviet Union, and with others.

The National Science Foundation was given lead responsibility. It continued in that role even after the National Oceanic and Atmospheric Administration was established as the principal civilian agency in marine affairs.

Epilogue

By 1971, the international arena had been beset by other events that dampened opportunities for ocean collaboration. The United Nations was caught up in a contentious atmosphere, exacerbated by Third World rhetoric. The hierarchy at the National Science Foundation and in the

scientific community saw the IDOE as just another science program and not as an instrument with which to synthesize scientific and public interests, especially on foreign policy. Neither followed the primary theme at IDOE's origin of synthesizing scientific with public purposes. In addition, the early flowering of international cooperation wilted as other nations failed to match even weak U.S. funding. Indeed, the IDOE neither earned high-level policy connections from succeeding administrations, nor funds.

To authors of the IDOE concept, the greatest disappointment was the growth in nationalistic initiatives in Law of the Sea negotiations; basic goals fell victim to short-term, parochial ambitions. A vigorous Decade, in time, might have completely altered that atmosphere. So, whatever its successes, and there were many, IDOE failed to meet its primary goal of heading off international conflict over intensified use of the sea by using collaborative exploration as a new and untainted means to achieve world comity.

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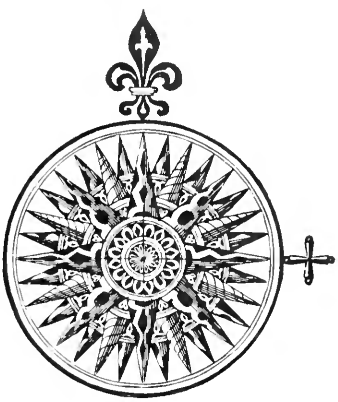


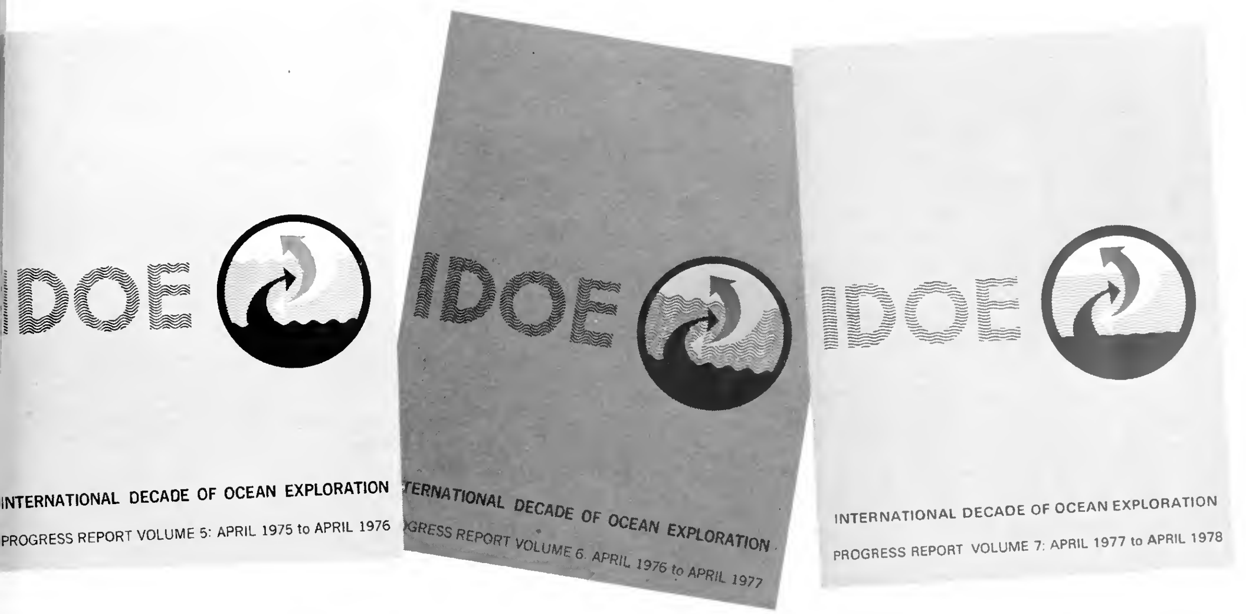
IDOE Acronyms

NORPAX	• North Pacific Experiment
CLIMAP	• Climate: Long-Range Investigation, Mapping, and Prediction
MODE	• Mid-Ocean Dynamics Experiment
ISOS	• International Southern Oceans Study
POLYMODE	• Polygon Mid-Ocean Dynamics Experiment
GEOSECS	• Geochemical Ocean Sections Study
CEPEX	• Controlled Ecosystem Pollution Experiment
SEAREX	• Sea-Air Exchange Study
PRIMA	• Pollutant Responses in Marine Animals
FAMOUS	• French American Mid-Ocean Undersea Study
MANOP	• Manganese Nodule Program (Phase 2)
RISE	• Rivera Submersible Experiment
SEATAR	• Studies in East Asia Tectonics and Resources
CENOP	• Cenozoic Paleo-Oceanography Project
CUEA	• Coastal Upwelling Ecosystem Analysis
SES	• Seagrass Ecosystem Study

Bureaucracy and Science: The IDOE

Launching IDOE miniature aircraft from deck of RV/Knorr. Air samples collected over the ocean by "MAC" were analyzed for light, volatile, halogenated hydrocarbons as part of Pollutant Transfer Program.

in the National Science Foundation



by Feenan D. Jennings and Lauriston R. King

The enduring legacy of the International Decade of Ocean Exploration (IDOE) will be new ideas and questions about the oceans and their role in human affairs. There is, however, another dimension to the IDOE. It involves the administration of the program — specifically the influence of the National Science Foundation (NSF) on the kind of program that evolved through the Decade of the 1970s.

Although a big part of the planning for the proposed IDOE had been done by officials of the Johnson Administration, the actual decision to go ahead was made by President Nixon. On October 19, 1969, Vice President Spiro T. Agnew announced the initial plans for United States participation in the Decade. Several weeks later, the Administration assigned responsibility for the planning, management, and funding of IDOE activities to the NSF.

The NSF then set up the Office for the International Decade of Ocean Exploration and chose three areas for priority attention: environmental quality, environmental forecasting, and seabed assessment. In 1971, living resources was added as a fourth program area.

The White House charge to the Foundation was backed with $15 million in new money. Translating the broad goals of the program into a $15-million research package called for a number of fundamental decisions involving relationships with other federal agencies, the nature of scientific management, and the selection and initiation of new projects within the four program areas.

A Place in the National Science Foundation

The National Science Foundation had not yet celebrated its 20th birthday when it was called upon to administer the Decade program. As a small executive branch agency with a fiscal year 1970 budget of $440 million, the NSF had been the main patron of basic academic research in the United States since the mid-1950s. Together with the U.S. Navy's Office of Naval Research (ONR), it had been the major source of support for oceanographic research. Emphasis on scientific understanding of the marine environment made the NSF a logical base for the IDOE. At the same time, however, the character and style of the NSF bureaucracy and the IDOE's place in it played an important role in the kind of program that evolved.

For example, one of the most important consequences of bureaucratic location is the ability to defend and promote a program. Figures 1 and 2 reflect the changing fortunes of the IDOE on the organization charts.

The IDOE was initially established as an Office reporting directly to the Assistant Director responsible for the newly created Directorate for National and International Programs. In 1976, however, another Foundation reorganization slipped the IDOE further down the administrative chain by locating it within the Division of Ocean Sciences. Here it became responsible to a Division Director who in turn reported to the Assistant Director for Astronomical, Atmospheric, Earth, and Ocean Sciences.

These shifts had several important consequences. The most significant was the visibility of the program to other important decision makers, particularly those in Congress and in the Office of Management and Budget. Because the IDOE had been a White House program, the IDOE staff felt that not only did it have a unique status among oceanographic programs, but that it deserved the special consideration that came from designation as a national program.

The fact was Congress did not seem to know that the IDOE existed, lodged as it was in the middle regions of the NSF bureaucracy. During the first six or seven years of the program, if anyone asked a single question about the IDOE, the staff counted it as a sign that someone knew and cared after all. We were confident that if only Congress — or at least the congressional staff — knew what IDOE scientists had begun to learn about the oceans, they would enthusiastically endorse our need for additional funds.

For example, from our slightly naive point of view, the maps showing the content and distribution of manganese nodules clearly demonstrated the value of the program. The prospect for improved long-range weather forecasts over the continental United States made

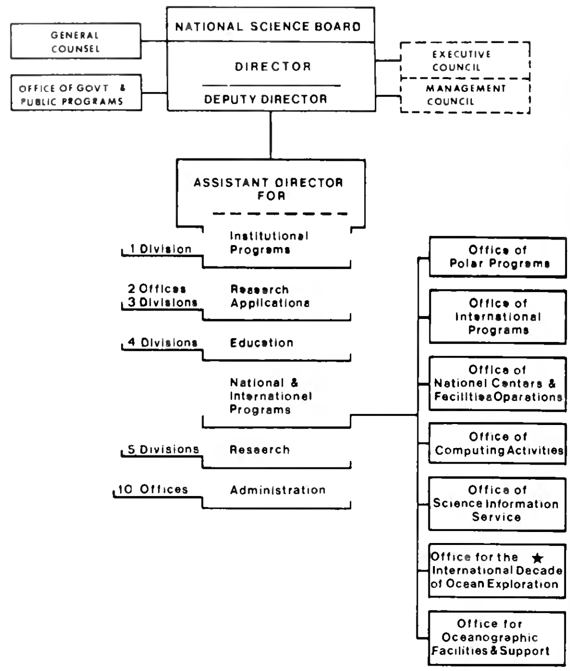


Figure 1. National Science Foundation organizational chart for 1969-1975.

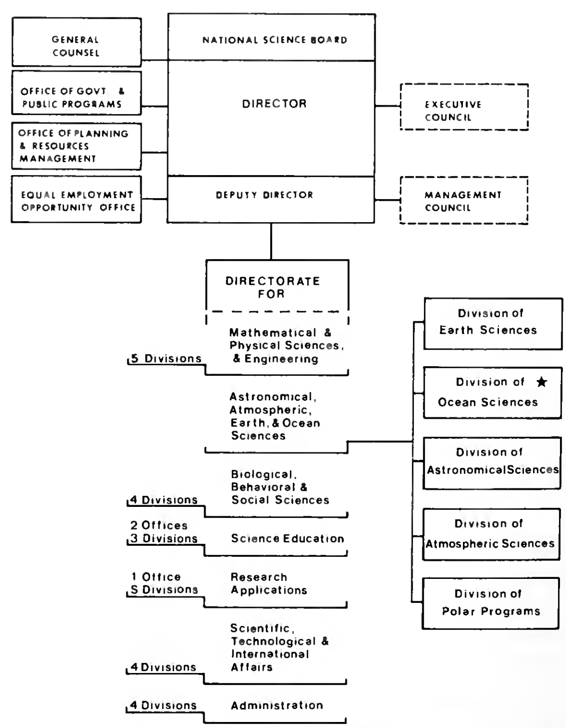


Figure 2. National Science Foundation organizational chart for 1975 to the present. ⋆ IDOE located within Division of Ocean Sciences.

possible by the North Pacific Experiment (NORPAX) was an obvious argument for increased support. And for sheer scientific excitement, unlocking the probable cause of the ice ages by probing the fossil record from deep-sea sediment cores in the Climate: Long-Range Investigation, Mapping, and Prediction (CLIMAP) project had few competitors. We were slow to appreciate the Washington wisdom that programs which seemed to be running well were of far less interest than those with obvious problems.

Toward the latter years of the Decade, however, it became apparent that anonymity had some virtues. With some modest stirring of interest on the part of the congressional staff concerned with oceanography, it became apparent that the prospects for mischief were every bit as good as the prospects for increased support. As a fairly small program tucked in a politically powerless agency, and long since stripped of the aura of the White House, the IDOE was especially vulnerable to a variety of hazards. These ranged from congressional staff skepticism of the IDOE approach to the General Accounting Office's questions about the overall conduct of the nation's oceanographic efforts. Although the IDOE was never the victim of these random actions, the opportunities for this mischief grew throughout the Decade.

The second important consequence of locating the IDOE in the NSF was that the IDOE became another claimant on the NSF's modest budget. For the IDOE to fulfill the role envisaged for it, the program required the total support and attention of the Foundation's top administrators. This was, of course, impossible. The NSF was responsible for research support across the full range of scientific disciplines. Executives in any organization are compelled to balance, shift, and juggle programs and people in ways that contribute to the overall interests of the organization, not just selected parts of it. Here the IDOE was another competitor for some share of the agency's slowly increasing budget.

A third consequence of IDOE's home in the NSF bureaucracy involved the character of the Decade's science program, and its relationship to the more conventional support for oceanographic research. The IDOE marked a major departure in the conduct of oceanographic research. Prior to the IDOE, marine research had been structured around small projects conducted by one or several scientists pursuing problems in the traditional oceanographic disciplines. The IDOE sought to complement this approach by supporting large-scale, long-term research, drawing on the skills and expertise of specialists from all disciplines. In terms of participation by scientists and institutions, project duration, and dollars spent, the IDOE was much larger and more complex than any single oceanographic program that had preceded it. Table 1 illustrates some of these features. Throughout its 10-year history, it supported 21 major projects, and totaled approximately $173 million.

This approach was not accepted with great enthusiasm by the ocean research community or the Foundation. Many oceanographers saw the big IDOE projects as squeezing out the smaller projects by chewing up increasing amounts of money and ship time. This wariness harmonized with similar sentiments within the Foundation where there has been a powerful institutional bias toward smaller-scale project research.

The tensions between these approaches, reduced to the mindless slogan of "big science versus little science," had some practical implications. The most significant was the Foundation's acknowledgment that both approaches were required to make big strides in oceanography, and that to do so required a balanced program. In fact, this balance was little more than fiscal parity between the IDOE and the oceanography project grant funding and had little relationship to the requirements of either program.

The place of the IDOE in the Foundation also had several implications for relations with the agencies that were to contribute to the goals of the program. As originally conceived, the IDOE was to be a collective effort on the part of all those federal agencies having ocean capabilities, with the National Science Foundation assuming lead responsibility. To boost the notion of the IDOE as a government-wide effort, about half of the first year's budget was pegged for redistribution to other federal agencies. It quickly became apparent that the missions of the other agencies, such as the U.S. Geological Survey (USGS) and the then recently created National Oceanic and Atmospheric Administration (NOAA), were sufficiently distinct from the NSF so that long-term, jointly funded, and fully integrated efforts were doomed from the start. Each agency had its own mission, its own history, and its own distinctive pattern of habits and procedures. In the absence of a program dictated from above, it was only natural that the agencies would continue to do what they felt they did best, and direct their funds into fulfilling their assigned missions. This was indicated in the early months of the IDOE.

Several agencies, particularly NOAA and USGS, were quick to submit proposals to tap the new money. This pass-through provision, where the NSF would allocate half of the new money to other agencies during the first year, created two problems. The first involved the poor reviews given to the agency proposals. The rigors of the peer review process, an integral part of Foundation procedures, was foreign to most of the research procedures for the mission agencies during the

Table 1. Major U.S. IDOE projects.

Programs Projects	Number of Institutions	Number of Scientific Investigators	Year Initiated	Expected Year of Completion	Estimated Total Cost (in millions of dollars)	U.S. Agencies Providing Funds
Environmental Forecasting						
NORPAX	28	45	1971	1982	29.7	ONR
CLIMAP	8	22	1971	1980	8.0	
MODE	16	45	1971	1974	8.0	ONR, NOAA
ISOS	9	16	1974	1981	10.2	NSF
POLYMODE	12	35	1975	1982	15.5	ONR, NOAA
Environmental Quality						
GEOSECS	14	28	1971	1980	23.5	ERDA
POLLUTANT BASELINE	17	30	1971	1978	2.3	
POLLUTANT TRANSFER	9	10	1972	1979	10.0	
BIOLOGICAL EFFECTS						
FIELD (CEPEX)	5	10	1973	1980	6.5	
LABORATORY	6	8	1973	1979	10.0	
SEAREX	9	15	1977	1983	4.6	
PRIMA	5	6	1978	1984	2.4	
Seabed Assessment						
SOUTH ATLANTIC MARGINS	2	15	1971	1975	4.0	
NAZCA PLATE	3	25	1971	1977	6.0	
FAMOUS	4	10	1972	1975	2.0	NSF/ONR/NOAA
MANGANESE NODULES	10	18	1972	1977	4.0	
MANOP	11	21	1977	1984	8.0	
GALÁPAGOS	3	9	1976	1979	1.4	
RISE	5	7	1977	1980	1.3	
SEATAR	7	15	1975	1980	5.4	
CENOP	11	15	1978	1982	2.8	SA/SGG
Living Resources						
CUEA	13	11	1972	1979	16.1	
SES	10	11	1974	1981	7.0	

early 1970s. Proposals that might have been suitable for gaining support within their respective agencies were not received favorably by academic reviewers.

The second problem was more difficult. It involved the failure of the agency proposals to address the broad goals of the IDOE, and instead to request support for projects more compatible with ongoing mission activities. For the IDOE to support this kind of research would have abdicated responsibility for the program by handing over large sums of money for projects that failed to mesh with the evolving program.

The final difficulty with a government-wide IDOE program was the simple fact that even where agency and program interests were similar, there were still enough differences in management style, funding philosophy, and long-range research objectives to sharply reduce the incentives for inter-agency collaboration. In the case of NORPAX, for example, the IDOE sought to support a joint program with the Office of Naval Research to examine the implications of Pacific Ocean sea-surface temperature anomalies on the continental weather over North America. Muddied lines of authority between the two federal patrons and the project scientists, different scientific objectives and review procedures, and budgetary stresses conspired to break down the initial efforts to integrate support and management by the ONR and the NSF. The project was restructured in a way that each agency funded those parts of NORPAX most appropriate for its own goals, and reduced formal management efforts in favor of regular but informal consultation.

Scientific Freedom and Public Accountability

Although the Foundation had been especially successful in reconciling the needs for scientific freedom and public accountability through its peer review process, the IDOE presented a special challenge. The goals compelled a basic scientific research program, but one that focused research in a way that promised to contribute to these goals

over a 10- to 20-year period. Meshing the interests of the oceanographers, the IDOE and its goals, and the requirements of the National Science Foundation, entailed special efforts at project selection, review, and management.

Early program announcements triggered a flood of proposals, most of which were closer to the traditional project grant than to the proposed IDOE approach of long-term, large-scale, multidisciplinary projects. This, combined with the eager claims of the other federal agencies, created a sense of excitement, frustration, and, at times, exasperation. There was a clear need to set some priorities, map some guidelines, and create some semblance of order to get a coherent program in the field.

Despite the existence of projects designed prior to the IDOE, but well suited to it, such as the Geochemical Ocean Sections Study (GEOSECS), the Mid-Ocean Dynamics Study (MODE), the Climate: Long-Range Investigation, Mapping, and Prediction (CLIMAP) project, the Southwest Atlantic Continental Margin (SWACM) project, and the Nazca Plate project, there were few other coherent efforts ready to go.

The need to organize the new program, particularly to pinpoint priorities that fit the goals of the IDOE, resulted in one of the most enduring contributions of the IDOE to oceanographic planning and management: the planning workshop. The premises were simple. First, given limited funds, it was necessary to concentrate dollars on problems most likely to lead to big advances. Second, administrators were rarely qualified to judge which areas would be the key to making advances across one or several fields of science, and, at the same time, relate them to the social goals of the program. Third, although specialists might have a powerful hunch about where their field ought to move, the presence of specialists from other fields tempers the kind of parochialism that pervades all professions.

Planning workshops were used with great success throughout the Decade. In addition to providing guidance to the IDOE staff, they also made it possible for scientists from a variety of institutions and disciplines to focus on key research problems, and, in several cases, design projects to tackle these problems. Once projects had been identified as appropriate for consideration by the IDOE, and proposals submitted, the well-established NSF peer review process played a critical role in the final selection of projects for funding.

Like most NSF projects, IDOE proposals were subjected to peer review. Unlike the practice in many parts of the Foundation, however, these proposals were sent for mail review, and then scrutinized by a panel of specialists. (Many sections in the Foundation relied almost exclusively on panel recommendations.) There were several twists in the process, however, that caused some discomfort for Foundation officials accustomed to the more traditional mail or panel review.

The research vessel Agassiz *of the Scripps Institution of Oceanography mooring a discus-hull buoy, which was used before NORPAX got underway to gather and transmit environmental data to a shore station. The information was then used to study the relationship between sea-surface temperature anomalies, the jet stream path, and the severity of winter as part of the North Pacific Experiment.*

One of the biggest difficulties was in reviewing not only for scientific excellence, but also for the needs of the project. Mail reviewers were quick to point out deficiencies in proposals, and to note the routine character of certain tasks. Often, however, these routine data-gathering, or monitoring activities, though not high science, were essential to a project. Panelists had to weigh the needs for each task against the mail reviews and decide whether or not to recommend it for funding, even though it may have received low or average ratings. These kinds of accommodations and adjustments then had to be argued through a Foundation chain accustomed to funding specific, high-rated projects.

The size, complexity, and funding levels of the typical IDOE project called for a degree of management with few precedents in oceanography. Management in this case meant both the effort needed to coordinate the scientists, ships, and equipment for extensive field experiments, and efforts needed to insure public accountability. Two decisions were made at the outset: first, that the IDOE projects would rest in the hands of the project scientists and, second, that

the IDOE staff would be kept to the minimum size needed to plan and supervise the research program.

The first decision meant that the scientific staff at the academic institution having prime responsibility for each major project would have to be provided with administrative and managerial staff. The exact structure varied from one project to another, depending on how the scientists organized themselves to carry out their work. Each project had a specific individual who was identified as the main link to the IDOE office.

In retrospect, it should have been obvious that our initial zeal to assure the Foundation that we really could delegate the management to the institutions and still exercise our responsibilities as trustees for grant funds would clash with the scientists' insistence on the greatest possible freedom to carry out their work.

In early 1972, in our review of the first large GEOSECS proposal, we arranged for several representatives of a successful systems management concern to travel to the Scripps Institution of Oceanography in La Jolla, California, to explain the value of their techniques for the project steering committee. After a heated discussion, we conceded that our approach might have been a bit heavy-handed. In turn, the GEOSECS group provided us with a detailed schedule on how they were going to accomplish all of the work required to begin the Atlantic sampling program by the target date of July 1973. We learned the limits of the patience of academic scientists for bureaucratic meddling and the academics realized that we were serious about assuring that they were organized to accomplish their scientific goals.

Trying to protect the scientists' freedom, and maintain some degree of accountability was at best frustrating, and at worst, a downright losing battle. One of the main causes for these troubles was Congress' growing scrutiny of NSF management practices. This resulted in demands that the alleged deficiencies be corrected by even more stringent internal review of funding decisions. Invariably, these outside pressures, translated through the NSF bureaucracy, were felt in the administration of the IDOE, particularly in the review process and the procedures for initiating new projects.

One new twist resulting from this congressional pressure was the creation of a review board within each directorate, plus a special review board for items requiring approval by the Foundation's governing group, the National Science Board.

The review boards compounded the prospects for delay and frustration in the movement of funds to researchers. More important, however, they elevated the importance of procedures to a point where administrative form rivaled scientific judgment as criteria for moving grant actions forward. Despite the grousing by the program managers, there was no systematic effort to determine whether or not the review boards or other embellishments to internal NSF procedures improved project accountability or the effectiveness of publicly supported research. The Foundation, with no political strength of its own, was ill-equipped to resist or temper these demands for even greater bureaucratization of project funding than already existed.

Congressional pressures to reform the peer review process also led the NSF to demonstrate that, like Caesar's wife, the peer review process not only was pure, but also gave no hint of impropriety. The result was a set of guidelines for the selection of reviewers that was excessive in its zeal to avoid all suggestion of biased judgment. They also made review of IDOE projects more difficult by restricting the use of reviewers from any university involved in a proposal, even though they were from different fields, or in different parts of the university. Under these conditions, most of the scientists from the major institutions were prevented from assisting in the review of the large IDOE projects because most of the institutions were participants.

The second consequence of these pressures to be more rigorous in the review process was the effort to get reviews on everything, even though certain categories of activities were hardly appropriate for the kinds of peer reviews used to evaluate scientific proposals. These involved requests for support for advisory groups like the National Academy of Sciences' Ocean Policy Committee or the Ocean Sciences Board, and service groups like the National Oceanic and Atmospheric Administration's Environmental Data Service (EDS).

To insure the availability of IDOE data, and to produce an annual progress report, the IDOE entered into an interagency agreement with the EDS. Most of the tasks the EDS agreed to do for the IDOE were special efforts, and not part of the regular services for other data center users. Annual proposals from the EDS were reviewed by IDOE staff and negotiated to reach a workable budget for these services.

As the NSF review process came under fire, however, it became necessary to get mail and panel reviews for just about everything, including the EDS agreement. In this case, peer review was inappropriate because service, not science, was the issue. Subjecting EDS proposals to review by academic scientists resulted in unfavorable comments, mostly on the grounds that the scientists did not want to see research funds used to support services provided by another government agency. We accepted EDS' arguments that they were indeed providing additional services for the IDOE which could not be accommodated in their regular budget, hence required additional support

from the IDOE. This was an IDOE management judgment. But the insistence on outside review by academic scientists led to delay and unnecessary frustrations as program managers sought to refute the negative reviews.

Another consequence of external pressures on the Foundation involved initiation of new projects. In the first half of the Decade, the workshops had worked extremely well to identify key problems, or shift the direction of existing projects. Frequently, workshop participants submitted proposals based on these sessions, a situation that gave rise to innuendos that the IDOE was a closed program. The same pressures at work on the Foundation's review process led to elaborate measures to demonstrate that these workshops were open to all interested scientists. If a group of scientists decided to mount a program, then they would advertise it to the community to make sure no one was left out. These efforts to open up the project initiation process may have struck a blow for the apparent democratization of science. At the same time they may have triggered an erosion of incentives that scientists had in starting and controlling their own projects. The fact remains that not all scientists are personally or professionally compatible.

These examples from the review process and project initiation procedures are only examples of the way external pressures on the Foundation affected administration of the IDOE. Certainly, they were time consuming, sorely trying the patience of scientists in the field. They had little demonstrable bearing on accountability or scientific productivity.

Conclusions

International politics, personal leadership, and bureaucratic skills all played a role in shaping the IDOE. This article has treated one narrow, specific aspect of the evolution of the Decade, the influence of the National Science Foundation on the program.

If the IDOE did not live up to the expectations of its designers, it was due, in part, to limited funding, the lack of readiness on the part of the oceanographic community to field large projects, and the embryonic skills of administrators and scientists for this type of research — and, in part, to unrealistic expectations. As a small, highly specialized executive agency, the NSF had neither the sizable budget nor powerful clientele to seize and sustain leadership throughout a government-wide decade-long program. The aura of the White House faded quickly as administrations changed, as new problems arose, and as those responsible for creating the Decade moved on. Inside the Foundation, the IDOE became yet another competitor for funds.

Despite these limitations, the NSF's experience in the promotion, defense, and administration of basic research made it the right

home for the IDOE. There was an appreciation by most foundation managers for the need to be flexible in the design and management of oceanographic research aimed at broad social goals. This administrative environment made it possible for academic oceanographers to pool their skills in ways that led to major scientific advances. For example, GEOSECS data will make it possible to model and predict the movement of large water masses as well as tackle problems such as the changing amounts of carbon dioxide in the atmosphere and oceans. Research conducted in the North Pacific on coastal upwelling and air/sea interaction should enhance understanding of the importance of large-scale events in the central equatorial Pacific for the abundant fisheries along the South American continent.

Despite the insidious growth of administrative red tape, and the gradual descent of the Foundation into bureaucratic mid-life, the NSF has for the most part provided a durable and sufficiently flexible base for large-scale oceanography. The success of large-scale, multidisciplinary efforts pioneered by the IDOE scientists has made it possible to continue this kind of research into the 1980s as a permanent capability within the Foundation.

Feenan D. Jennings, presently Director of the Texas A&M University Sea Grant Program, was head of the National Science Foundation Office for the International Decade of Ocean Exploration (IDOE) from 1970-1978. Lauriston R. King, Deputy Director of the Texas A&M University Sea Grant Program and Assistant Professor, Department of Management, was a Program Manager in the IDOE office between 1972 and 1978.

Assessing the Seabed

A manganese nodule.

by E. M. Davin and M. G. Gross

Study of the ocean basins was a key component of the International Decade of Ocean Exploration (IDOE). One early concern was assessing the processes that form deep-sea manganese nodules. A second theme was understanding the effects of plate tectonics on ocean floor processes, such as those which form mid-ocean ridges and ore deposits. And finally, a unique contribution of the sea-floor studies was the deciphering of changes in oceanographic conditions during the Pleistocene glacial period. In short, the studies of the ocean floor supported by the IDOE ranged from assessing the processes that produce valuable and strategically important minerals to improving our understanding of the processes that control and change our climate.

During the 1970s, geology and geophysics projects supported by IDOE, combined with results obtained from the Ocean Sediment Coring Program, reshaped our thinking about the ocean floor. To show the range of advances in the geology and geophysical understanding of the ocean floor during the Decade, we will review some of the projects and their contributions.

One of the first projects in marine geology and geophysics was a study of the passive continental margins in the South Atlantic (see *Oceanus*, Vol. 22, No. 3, p. 48). Objectives were to study the origin and evolution of passive continental margins and their relation to hydrocarbon accumulation. The Woods Hole Oceanographic Institution (WHOI) concentrated on the west coast of Africa (southeast Atlantic) from Capetown to Lisbon, and the Lamont-Doherty Geological Observatory (LDGO) on the east coast of South America from the Scotia Arc to the Caribbean. Underway geophysical observations (seismic reflection, sonabuoy refraction, gravity, and magnetics) were made from the Mid-Atlantic Ridge to the continental margin, where a thick

wedge of sediments obscures the basement reflection. Both institutions cooperated on a two-ship refraction study of the Amazon cone. Scientists from South American and African countries participated in cruises and data analyses. Extensive logistics support was supplied by Argentina, Brazil, and South Africa.

The South Atlantic was selected because it displayed the best tectonic fit between the two continents before breakup of Gondwanaland *; therefore, the stages of separation could be more easily followed. Moreover, elongated sedimentary basins are found along the coastal areas paralleling the direction of sea-floor spreading. Some of the basins contain "giant" oil fields, notably in Brazil and Nigeria. The project provided broad-scale regional tectonic data that helped place the stratigraphy and structure of the individual oil provinces in their tectonic setting.

Considerable data were collected from east-west trending fracture zones (transform faults) that extend across the South Atlantic and into the continental land mass of South America and Africa. The breakup of the two continents can be traced along these fracture zones (Figure 1). One major zone intersects the continent at Brazil to form the Amazon River basin; similar conditions initiated the Niger River basin in Africa. The southeast margin of South Africa separated the Malvinas Platform (Falkland) from southwest Argentina along a margin fracture zone. Seismic reflection data led scientists to reconstruct the opening of the South Atlantic, revealing evidence of tectonic activity, such as the initial rifting of the continents and their drifting apart, with subsequent subsiding of the ocean floor, and sedimentation in the new ocean basins.

A time/space matrix could then be developed that shows the stratigraphy and structure of each major phase of opening. Figure 2 is a composite of the major types of sedimentation associated with a phase of tectonic evolution. As the continent (Gondwanaland) breaks up, symmetrical conditions are found on each side of the mid-ocean ridge spreading center, although not all five types occur along any one traverse. As the continents pull apart, the older (pre-Cambrian or Paleozoic) basement forms block faults. Some collapse into grabens,

*Edward Suess, in 1885, suggested that all the southern continents had once been joined as a supercontinent that he called Gondwanaland.

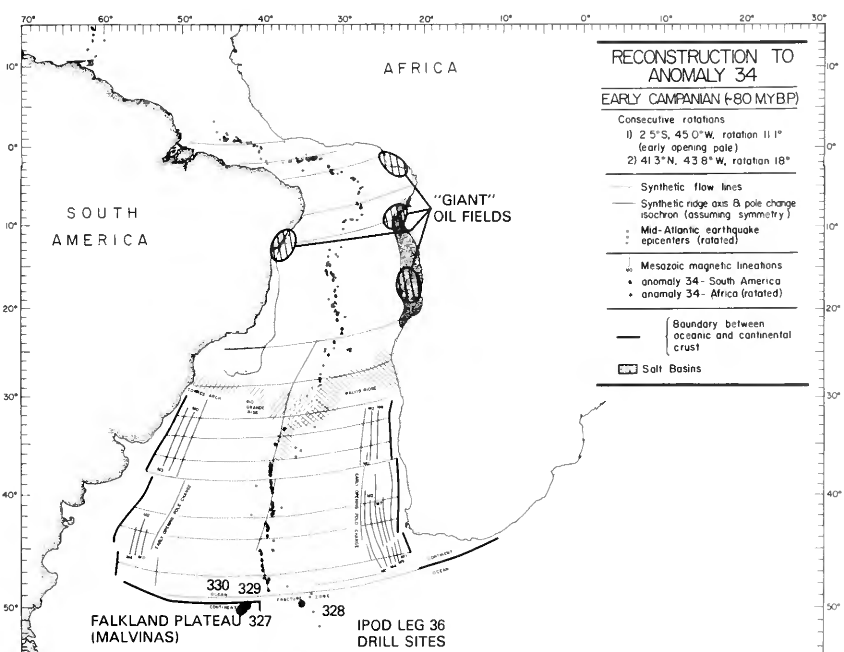


Figure 1. Opening of South Atlantic about 80 million years before present, showing key factors in sea-floor spreading: flow lines following transform faults; earthquake epicenters, salt basins, boundaries between oceanic and continental crusts, major seismic ridges (Walvis and Rio Grande Rise); continental plateaus between Argentina (Falkland/Malvinas) and South America.

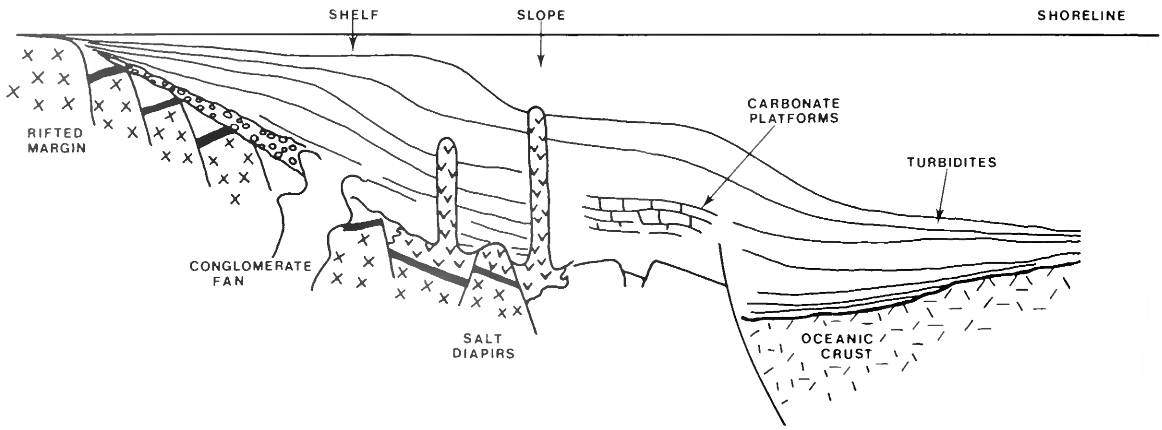


Figure 2. Composite diagram of a passive continental margin of the Atlantic type. Vertical scale ~ 20: 1 exaggeration.

where they are filled with clastic sediments, especially in front of large drainage systems, such as the Niger, Congo, and Amazon rivers. As basement subsidence and tilting continues, marine sediments are deposited in restricted shallow marine conditions (see *Oceanus*, Vol. 22, No. 3, p. 2). Thick deposits of evaporites form, succeeded by carbonate buildups and beach sands. Finally, a new and different type of hydrocarbon prospect, turbidites, form in broad anticlines down-dip from and in front of major deltas. This is indicated from seismic sections and International Program of Ocean Drilling (IPOD) data.

Manganese Nodules

An investigation of the origin and distribution of manganese nodules and the processes by which they selectively concentrate copper and nickel was one of the first major projects under Seabed Assessment. In 1972, under the impetus of the late Maurice Ewing of Lamont-Doherty Geological Observatory, a workshop/symposium was convened to determine the present status of knowledge and recommend a program of research. More than 100 scientists from industry, universities, and government participated, including many from foreign nations. Workshop topics covered scientific research, environmental impact, deep-sea mining technology, and the economic and legal implications of such mining. Subsequent IDOE support emphasized research into the basic scientific questions of nodule formation and distribution.

All available data — such as that in core laboratories, data banks, and files — were compiled and synthesized. A series of synoptic maps of the metal content by weight percent and their distribution over the world's oceans was published and widely distributed. Figure 3 shows the content of copper and nickel in the nodules for the northern Pacific Ocean.

The north central Pacific (near the Hawaiian Islands) was identified as the zone where the nodules have the highest metal content. A team of American scientific investigators proposed that a comprehensive field and laboratory program be initiated by IDOE to relate the high metal content to the local geological conditions. Data gathering was concentrated along a transect that both academic and industrial scientists agreed could serve as a potential mining site. In addition to dredge sampling and piston cores, bathymetric measurements, side-scan sonar, and high-resolution TV pictures were obtained. The results provided a broad-scale picture of the conditions under which nodules form, but the mechanisms for concentrating specific metals are still under investigation and open to interpretation.

Finally, the research community decided that the several processes could be understood quantitatively only by long-term, in situ measurements of the flux between ocean bottom water and adjacent sediments. To achieve this goal, a Bottom Lander was designed and is now undergoing development. Surveys (using deep-tow instruments) of prospective sites for detailed study using the vehicle are now underway. Sites will be selected in each of the five major sedimentary provinces of the Pacific: siliceous ooze, calcareous ooze, metalliferous sediment, hemiplagic clay, and red clay. Contrasting evidence from areas where metal contents differ both in kind and amount will add to our understanding of the process of nodule formation.

Project FAMOUS

A major advance in geological-geophysical research came from using research submersibles to study the

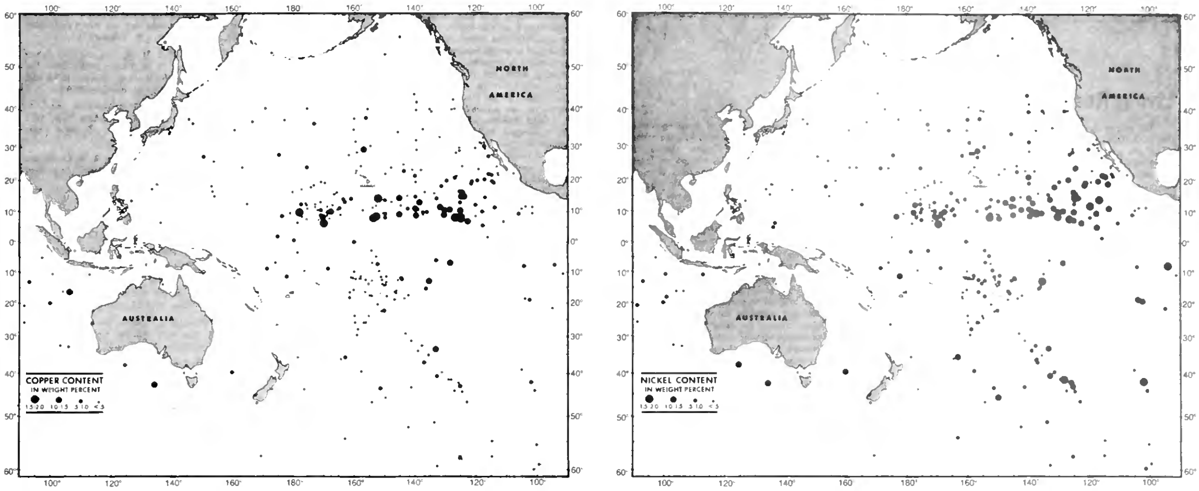


Figure 3. Copper and nickel content in manganese nodules in the Pacific Ocean.

ocean floor. The French-American Mid-Ocean Undersea Study (FAMOUS) project was the first to use manned deep-diving submersibles to observe formation of oceanic crust on the Mid-Atlantic Ridge southwest of the Azores in water 2,700 meters deep (Figure 4). The American and African crustal plates are separating there at a rate of 2 to 3 centimeters per year.

A bathymetric map, based on multi-narrow-beam echo-sounding data and photo mosaics from bottom photography, disclosed the most promising dive sites. Also, microearthquake studies and heat-flow measurements helped identify the most active areas. In 1974, the French bathyscaphe *Archimede*, and diving saucer *Cyana*, and the U.S. submersible *Alvin*, operated by the Woods Hole Oceanographic Institution, made 30 dives (see *Oceanus*, Vol. 18, No. 3).

The dives showed that the ridge crest has a fault-bounded central valley about 1 kilometer deep and 2 to 4 kilometers wide. Volcanic rock is extruded across the width of the floor, but is especially concentrated along a line of central volcanic hills (Figure 5). Systematic compositional variation in the lavas across the valley floor apparently reflects a zoning or evolution in the underlying magma chamber. However, several lava flows with discrete geochemical characteristics may result from mantle-derived magma moving into the chamber. This compositional zoning is one of the most important discoveries made by the FAMOUS scientists, and so far has not been documented at any other location.

As in other spreading centers, the Mid-Atlantic Ridge at the FAMOUS site is broken into segments, each several tens of kilometers long and separated by transform faults. Two fracture zones were studied extensively through photography, dredging, and submersible dives. Surprisingly little evidence of recent faulting was observed, although microearthquakes are frequent along the faults. Samples of hydrothermal deposits were recovered from both fracture zones, although no active vents were observed there or in the median valley.

FAMOUS played a critical role in understanding the active processes along oceanic ridges. First, it demonstrated that detailed geological mapping of rough, deep-sea terrain could be done by submersibles. Second, it helped define the nature of the essential components in the sea-floor spreading process: a narrow rifted valley with an axial volcanic ridge fed by an underlying magma chamber. These essential features proved to be common to spreading centers in other areas, where faster spreading made them more difficult to recognize.

Nazca Plate Studies

As the plate tectonic concept evolved, the association of major metal deposits within the upper (landward) plate overlying subduction zones was recognized. The Nazca Plate (Figure 6) off the west coast of South America was studied for its tectonic plate cycle, including the generation of new crust along the East Pacific Rise (EPR) and processes at the zone of continental plate collision where oceanic plate is partly subducted along the Peru-Chile Trench and assimilated beneath South America.

Study of the oceanic crust showed that pillow-shaped basalt formations are extremely abundant. Chemically, the crust was fractionated as the magmas (molten rocks) cooled during formation and minerals that formed early (primarily plagioclase and olivine) were removed, a process known as fractional crystallization.

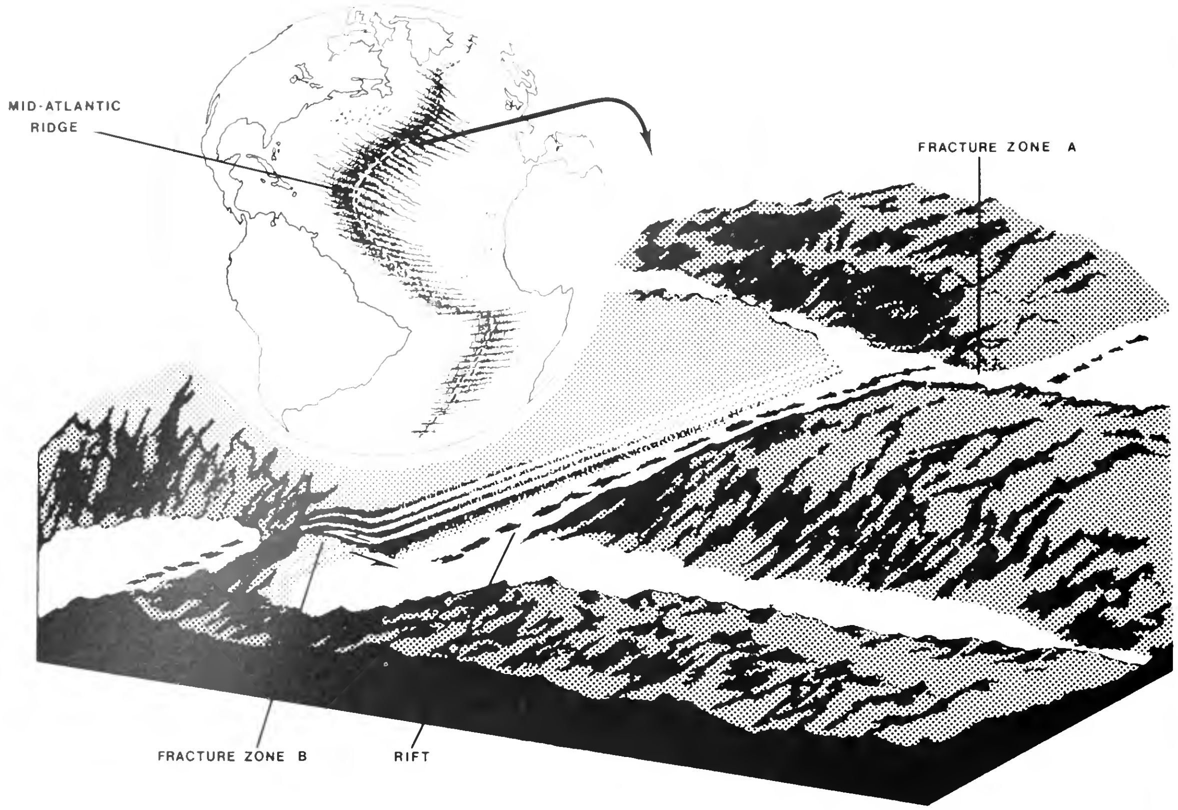


Figure 4. Location of the French-American Mid-Ocean Undersea Study, Project FAMOUS. (Adapted from National Geographic Society)

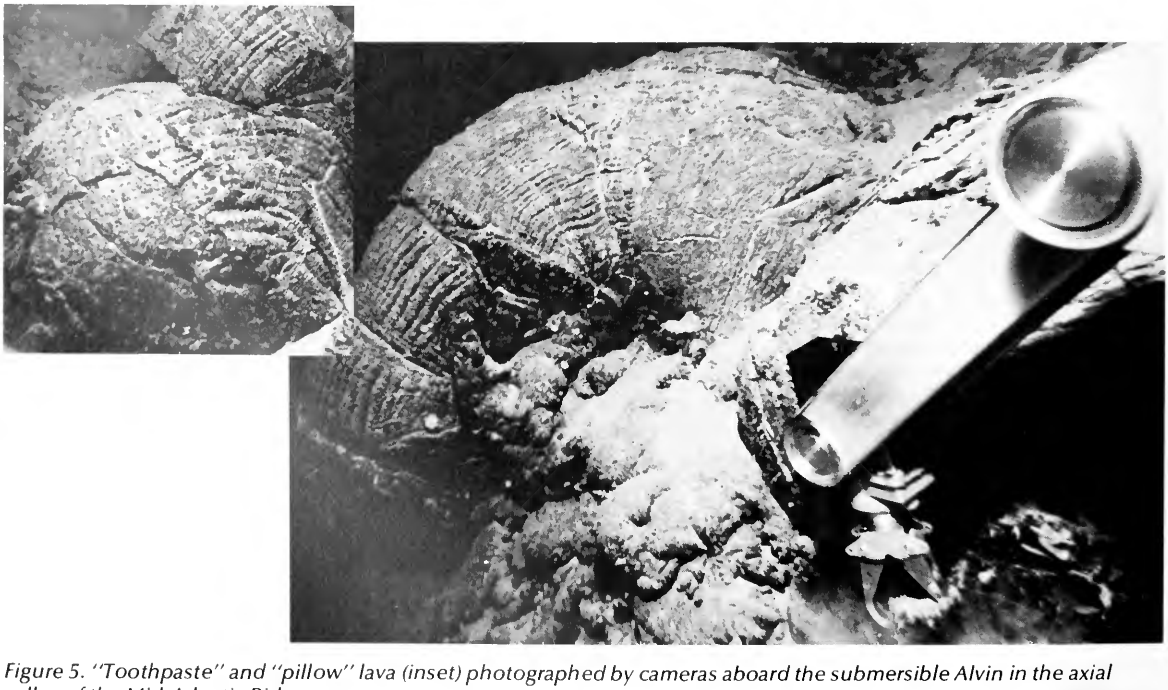


Figure 5. "Toothpaste" and "pillow" lava (inset) photographed by cameras aboard the submersible Alvin in the axial valley of the Mid-Atlantic Ridge.

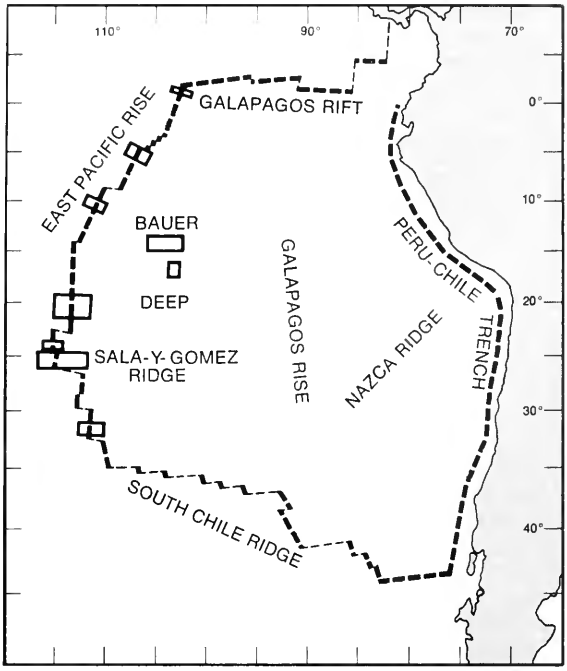


Figure 6. The Nazca Plate off the west coast of South America. New crust is being generated along the East Pacific Rise.

Metalliferous deposits on the Nazca Plate were found to be formed at low temperatures, in chemical equilibrium with seawater. The sediment studies indicated the importance of reactions between seawater and newly formed basalt at the mid-ocean ridges, a form of low-temperature submarine weathering. Distribution of individual elements in the deposits was controlled by 1) the sources of materials (hydrothermal reactions, accumulations of biological debris, and silicate material), 2) transport by bottom currents, and 3) local chemical transformations of hydrothermal deposits into more stable forms (clays, and iron and manganese oxides).

The "geo-still" concept combined some of the fundamental processes of plate tectonic theory and it was implicit in the Nazca Plate studies to explain the sources, path, and process of concentrations of porphyry copper formations. New crust rises to the surface of the ocean floor along active mid-ocean ridge spreading centers (Figure 7). Metalliferous sediments, particularly rich in copper, are deposited along the flanks of the spreading center.

According to the "geo-still" concept, a major portion of the sediments on the moving plate descends into the subduction zone. As the plate reaches mantle depths, materials are heated and ore-forming solutions move into the overlying rocks while refractive materials remain in the mantle. Molten rock (magma) rises in large batholiths to within a few kilometers of the surface. As the magma cools, copper is concentrated in deposits near the top of the formation. Erosion subsequently exposes these deposits for exploitation. Material collected during the Nazca Plate project, especially geochemical data, allows important constraints to be placed on this model. The geographic distribution of metals, relative to the subduction zone, and elemental and isotopic tracers of the geo-still theory have been critically evaluated, but no proof or consensus has evolved. A major constraint has been the scarcity of comparably detailed data on the structure and occurrence of mineral deposits in the Andes.

Galápagos and Rivera Hydrothermal Processes

The importance of submersibles also was dramatically illustrated on the Galápagos Rift in 1977 and at 21 degrees North on the East Pacific Rise in 1979. Scientists observed submarine hot springs on the sea floor, around which new mineral deposits were forming. These springs also support extraordinary communities of filter-feeding organisms, which live off bacteria that grow on the hydrogen sulfide exuded from the vents.

These features were first observed at the Galápagos Rift in 1977 (Figure 8), and then more extensively in 1978 and 1979 in a larger-scale cooperative program among French, Mexican, and American scientists at the Rivera Fracture Zone off the west coast of Mexico near the mouth of the Gulf of California (Figure 9).

Seawater circulates through newly formed oceanic crust, removing heat and reacting chemically with the rocks. Recently formed volcanic rock (erupted at temperatures of about 1,200 degrees Celsius) causes very hot waters to be discharged at temperatures of about 350 degrees Celsius through vents on the ocean floor. These vents have been observed on the East Pacific Rise project off Mexico.

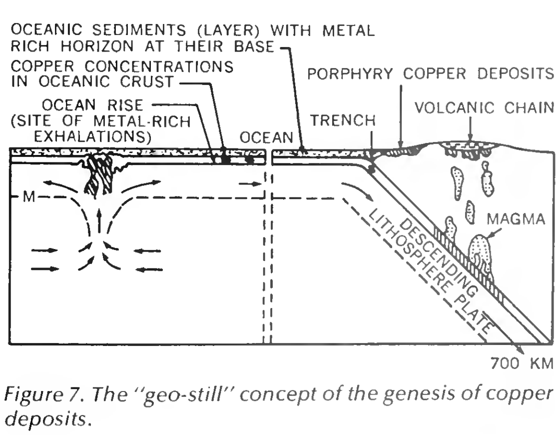


Figure 7. The "geo-still" concept of the genesis of copper deposits.

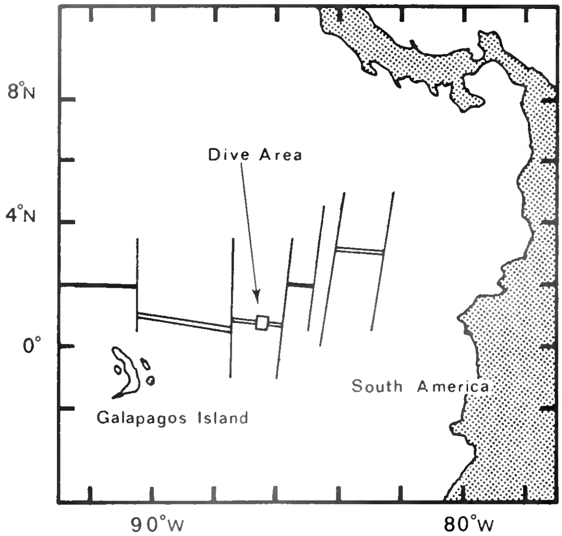


Figure 8. Location of survey area on Galápagos Rift.

Vents occur on fresh basalt in clusters and narrow bands about 250 meters across and several kilometers long. Individual vents form irregular chimneys nearly 10 meters high and about 4 meters across. The discharges, 1 to 2 meters per second, form dark, smoke-like plumes in the overlying waters (Figure 10). The scientists who first saw the vents in 1979 called them "black smokers," and compared the whole vent area to Pittsburgh in the 1920s.

The chimneys are made of silica and metal sulfides, including copper, nickel, cadmium, and sulfur. At temperatures of 300 degrees Celsius, seawater has a density of 0.7 grams per cubic centimeter so it rises in a buoyant plume that carries away freshly precipitated metal sulfides. These

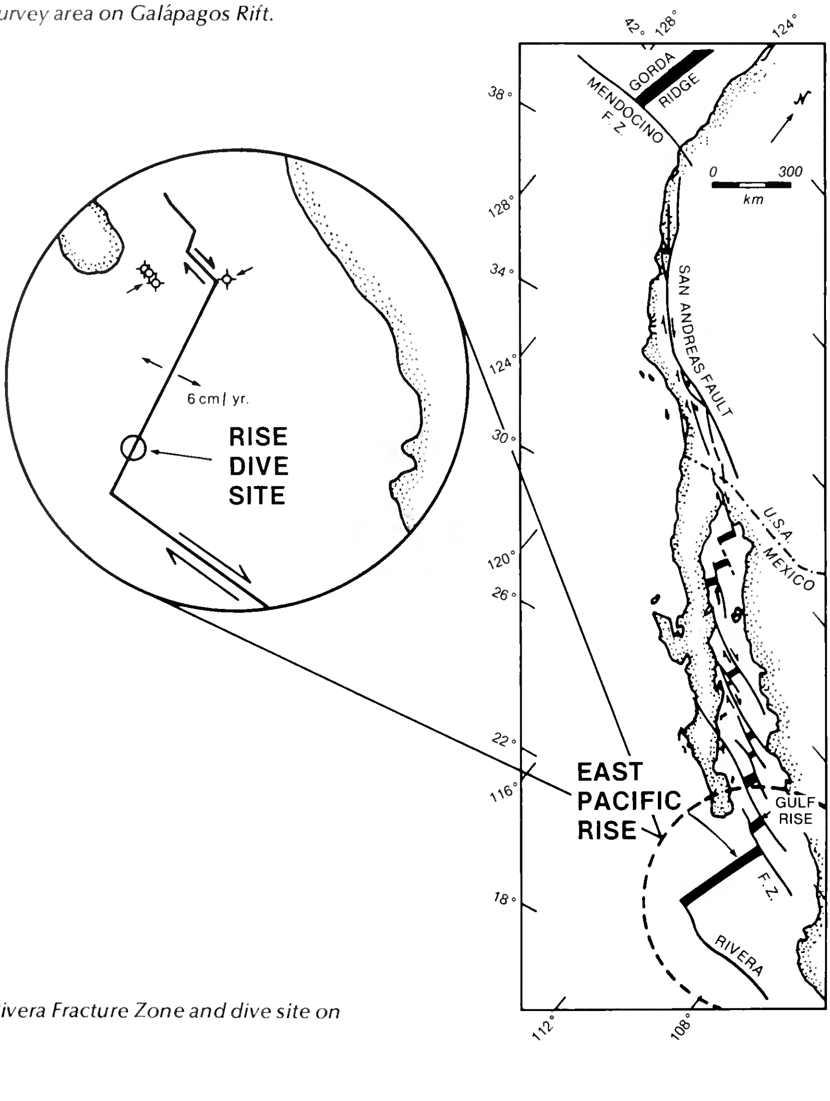


Figure 9. Location of Rivera Fracture Zone and dive site on the East Pacific Rise.

sulfide particles settle nearby in enriched ridge crust sediments in sulfides. Nearby ridge crust sediment deposits are characteristically enriched in copper, nickel, cadmium, chromium, and uranium. Similar deposits of these sulfides exposed on land have been mined as important ores, particularly on the islands of Cyprus and at locations in Japan.

Seawater continues to circulate, penetrating deeply into the newly formed crust and discharging through fissures on the ocean bottom. These discharges are 5 to 25 degrees Celsius and mix quickly with the cold ocean bottom waters (typically around 2 degrees Celsius). These cooler vents also support large populations of filter-feeding tube worms, clams, and mussels (see *Oceanus*, Vol. 22, No. 2). Inactive vents are surrounded by shells of dead organisms because the food supply is dependent on continued discharge of sulfidic waters. The waters from the inactive vents contain elevated concentrations of dissolved helium-3 and hydrogen sulfide, the former of which escapes, along with other primordial gases, from the mantle.

Studies in East Asia Tectonics and Resources (SEATAR)

The island arcs of the western Pacific and East Asia have long served as testing grounds for theories of earth processes. Two major areas of interest combined to form the program called Studies in East Asia Tectonics and Resources (SEATAR). Several scientific investigators from universities in the developed countries, including the United States, have worked independently on marine and land-based geological and geophysical problems, while other researchers from East Asian countries, especially in the less developed nations, have been exploring for mineral resources, including hydrocarbons, under the guidance of the United Nations Development Program through the Committee for Coordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas (CCOP).

American investigators, where their research interests coincided, selected three transects identified by CCOP scientists: Sunda (Indonesia) Island Arc (3), Banda Arc (4), and the Philippine Transect (5). The Philippine Transect was subsequently extended to include the Mariana island-arc system (Figure 11). SEATAR scientists have been seeking to understand processes along converging margins of the lithospheric plates; how these processes generate island-arc systems; how island arcs coalesce to form continental land mass; how minerals are mobilized into economic ore deposits; and the processes of hydrocarbon genesis and accumulation.

The first step was to prepare a Geophysical Atlas of East and Southeast Asian Seas. This atlas represented a compilation and synthesis of all available data from 45 degrees North to 15 degrees South and 90 to 150 degrees East.

Field work in SEATAR included studies of the Mariana island-arc system: volcanic arc-trench, fore-arc basin, and back-arc basin. Analysis of the relatively simpler conditions in this system is critical to interpreting other island-arc systems in more advanced stages of evolution. The second major area of study was the Indonesian (Sunda) Island Arc. The third area, the Banda Arc, is at the end of the Sunda Arc and provides a rare opportunity to examine an active collision between an island-arc system with continental margins (Australia). The fourth area, northern Luzon and adjacent offshore areas, involves an investigation both of an

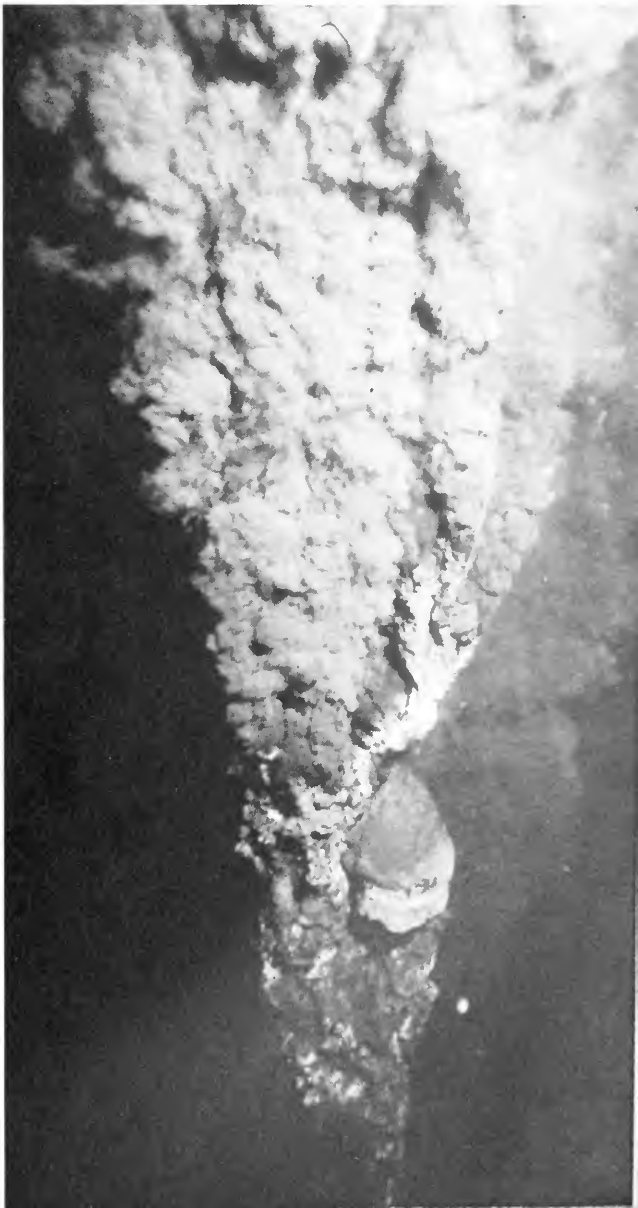


Figure 10. "Black smoker" on the East Pacific Rise. (Photo by Robert Ballard)

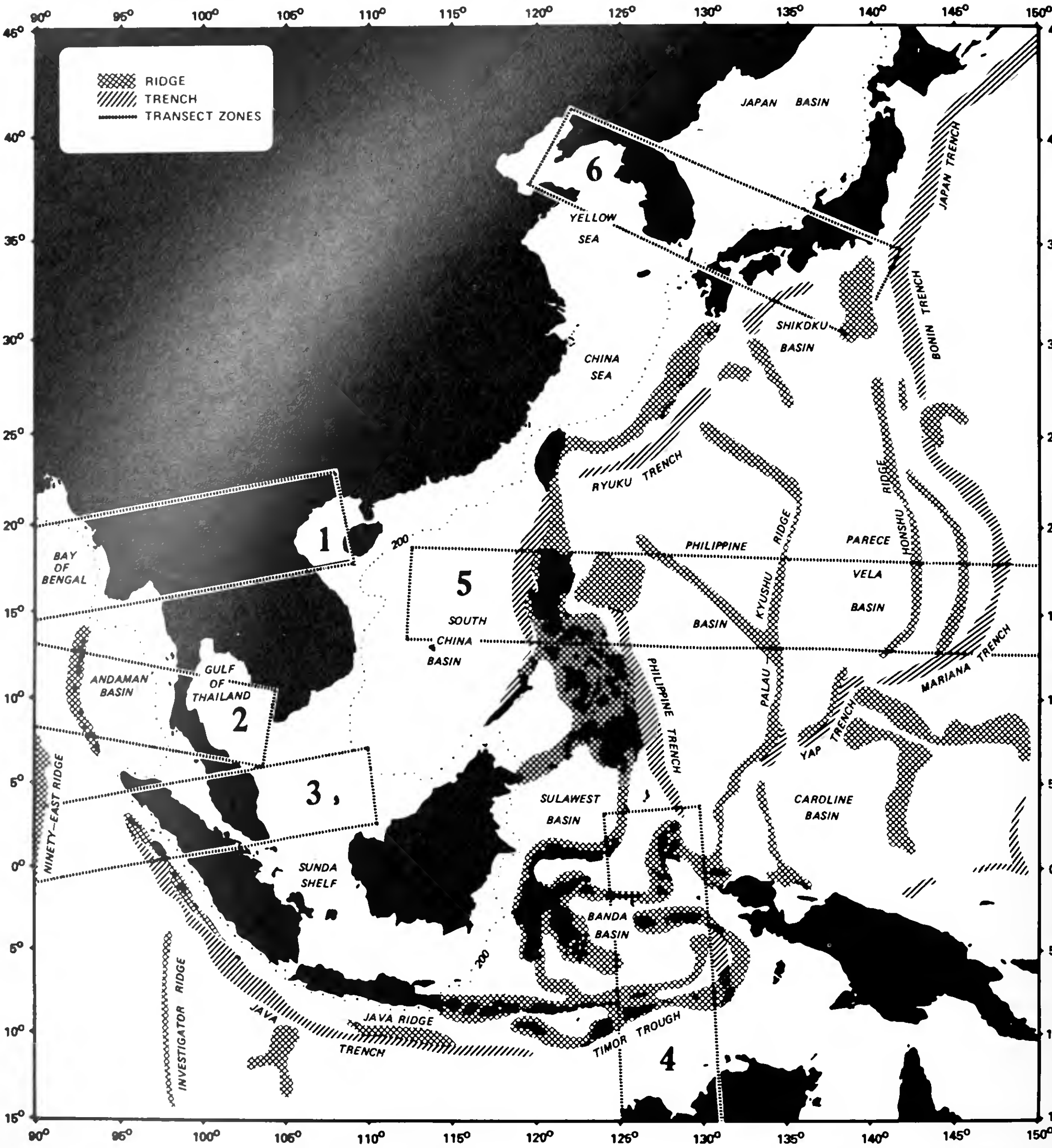


Figure 11. Transect areas where SEATAR scientists seek to understand the processes of converging lithospheric plates include the Philippine Transect (5), the Banda Arc (4), and the Sunda (Indonesia) Arc (3).

ophiolite* terrain (see *Oceanus*, Vol. 22, No. 3, p. 23) that appears to be intact and, at the same time, the still active processes by which it could have been emplaced.

Relatively denser crust descends into the earth's mantle in the Mariana island-arc system (Figure 12). At depths of 90 to 100 kilometers the descending slab begins to melt and magma rises toward the surface, forming volcanic island arcs. The depressed area between the volcanic arc and trench gradually fills with sediments forming the fore-arc basin. Other magmas (of unknown origin) rise to the surface along the Mariana back-arc basins, creating a spreading center along which new crustal material forms at the surface. It was in this area that evidence of hydrothermal activity was found in 1978. Further investigation of this phenomenon is needed because ore deposits formed in volcanogenic massive sulfide formations on land appear to have formed in a back-arc basin environment. Moreover, back-arc basin volcanism may have been the environment for the formation

*Ophiolites are slabs of oceanic crust that have been broken off during the subduction process and have been pushed onto continents and island areas.

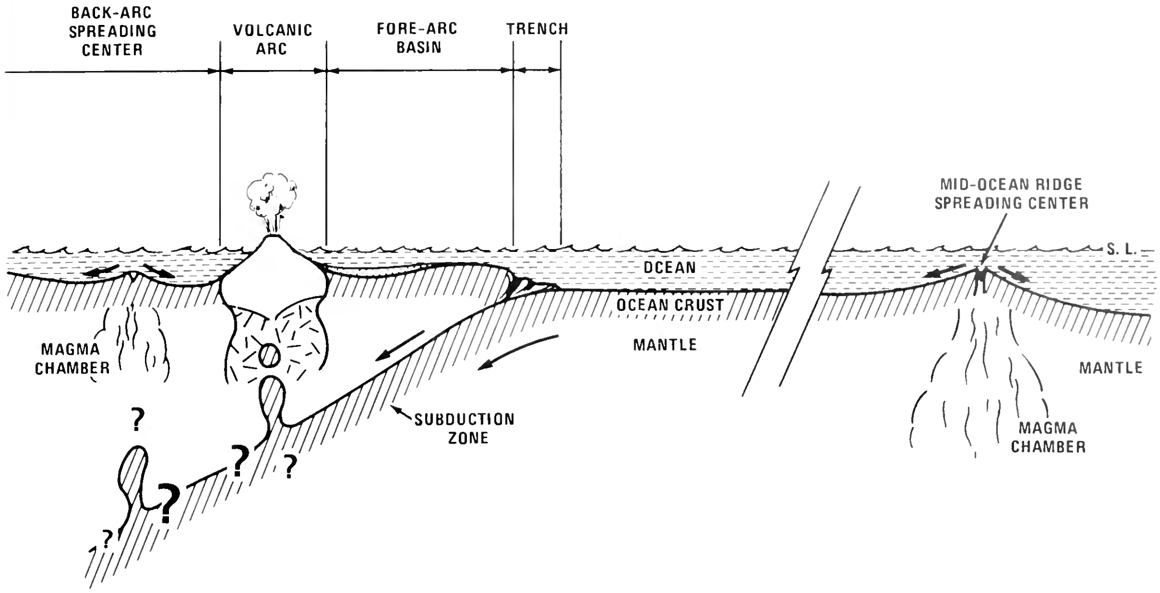


Figure 12. The Mariana island-arc system.

of ophiolite terrains, a major example of which is being investigated in northern Luzon (Zambales Range).

In the Sunda Arc, the area between the volcanic island of Sumatra and the non-volcanic offshore islands is a fore-arc basin in an advanced stage of development (Figure 13). Thick sediment deposits derived from the Bengal Fan are partly scraped off the descending slab to form a ridge (or chain of islands) that dams up sediment deposited in the fore-arc basin. This wedge of sediment forms the outer-trench slope and, where it rises above sea level — for example, Nias Island — a chain of non-volcanic islands parallels the Java Trench. Off the island of Java, at a distance uninfluenced by the Bengal Fan sediments, the accretionary wedge does not rise above sea level, a condition indicative of an intermediate stage of fore-arc basin development.

At the eastern end of the Sunda Arc, the Banda Arc turns 180 degrees in what is considered to be one of the earth's most striking tectonic features. The Banda Arc region is the most youthful collision

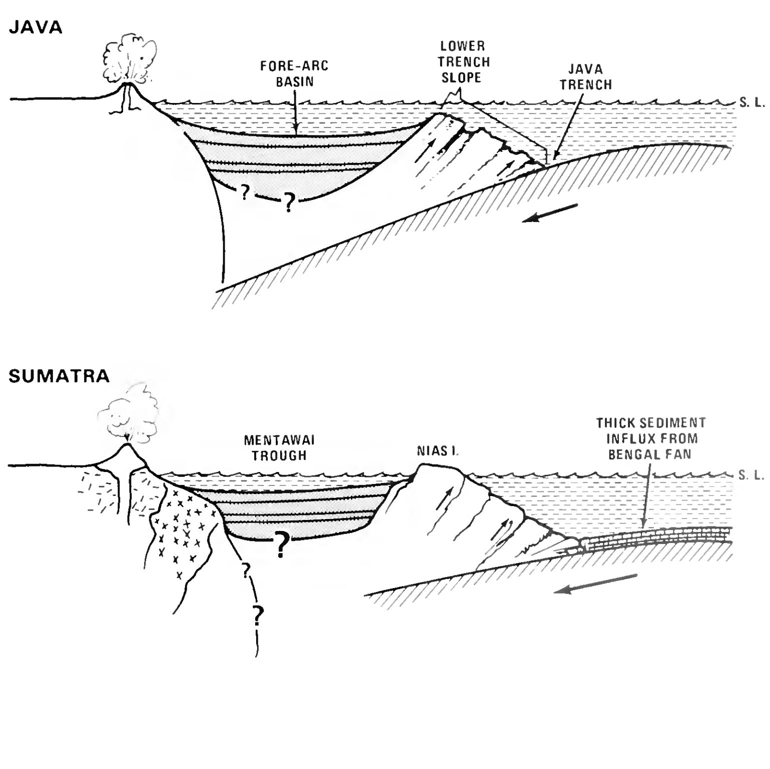


Figure 13. The Sunda Arc — Indonesia fore-arc basin.

of an island arc with the (Australian) continental margin.

The northern limit of the arc, for example, now appears to be pieces of an older land mass. The apparent subduction of continental crust under oceanic crust is now seen as a block of continental crust depressed by 5 kilometers during the collision and not subducted, in the conventional sense of the term.

The tectonic evolution of northern Luzon is shown in Figure 14. Approximately 25 million years before present (my BP) conditions were similar to those found in the Marianas today. A west-dipping subduction zone developed under the active northern Luzon volcanic arc; in the back-arc basin new crustal materials rose along the spreading center (the early stages of ophiolite formation). In the second sequence (~10 my BP), west-dipping subduction ceased and east-dipping subduction was initiated. The east-dipping subduction plate, and the back-arc basin spreading center (now dormant) moved eastward toward the subduction zone. In this interpretation, a sliver of basin crust, trapped behind the trench subsequently was scraped off to form part of the lower trench slope. This lower trench slope served as a dam for the sediments in the fore-arc basin (now the central basin of Luzon). As the process of subduction continued, the assemblage of rocks that form the fore-arc basin and lower trench slope were transferred to the land mass of central Luzon, and a new fore-arc basin and trench, the Manila Trench, was formed.

CLIMAP

The CLIMAP project (Climate: Long-Range Investigation, Mapping, and Prediction) contributed significantly to the history of global climate by reconstructing the surface of the earth during a typical August (Figure 15) and February at the height of the last ice age (18,000 years ago). The mapping delineated 1) the extent and thickness of land- and marine-based ice sheets, 2) the vegetation patterns, 3) the global sea level, 4) the seasonal

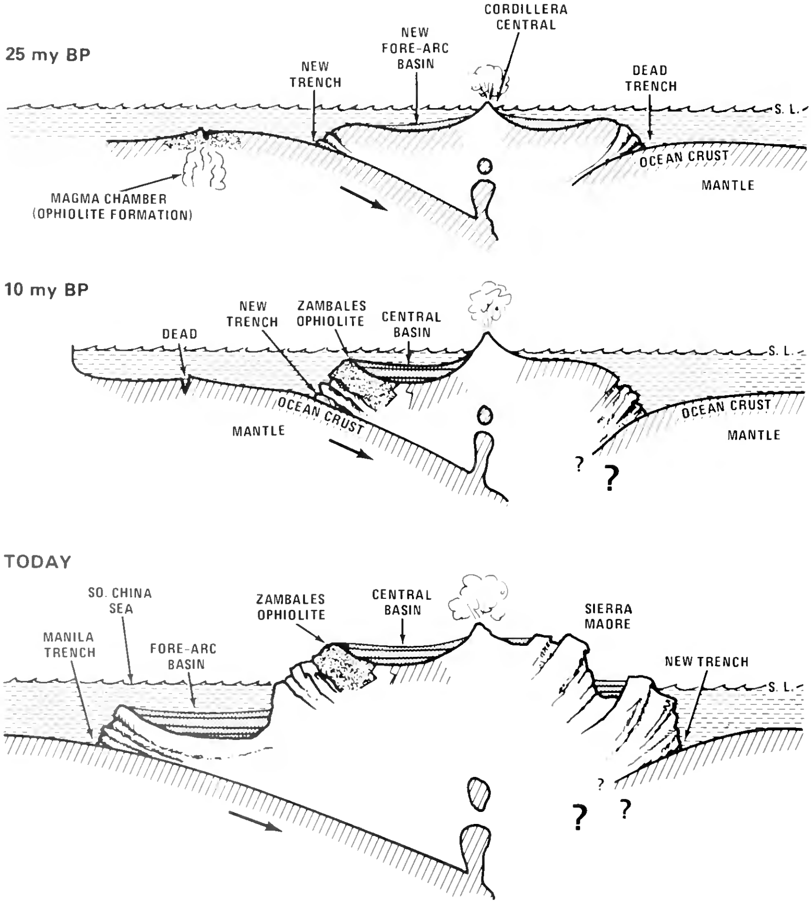


Figure 14. The tectonic evolution of northern Luzon, Philippines.

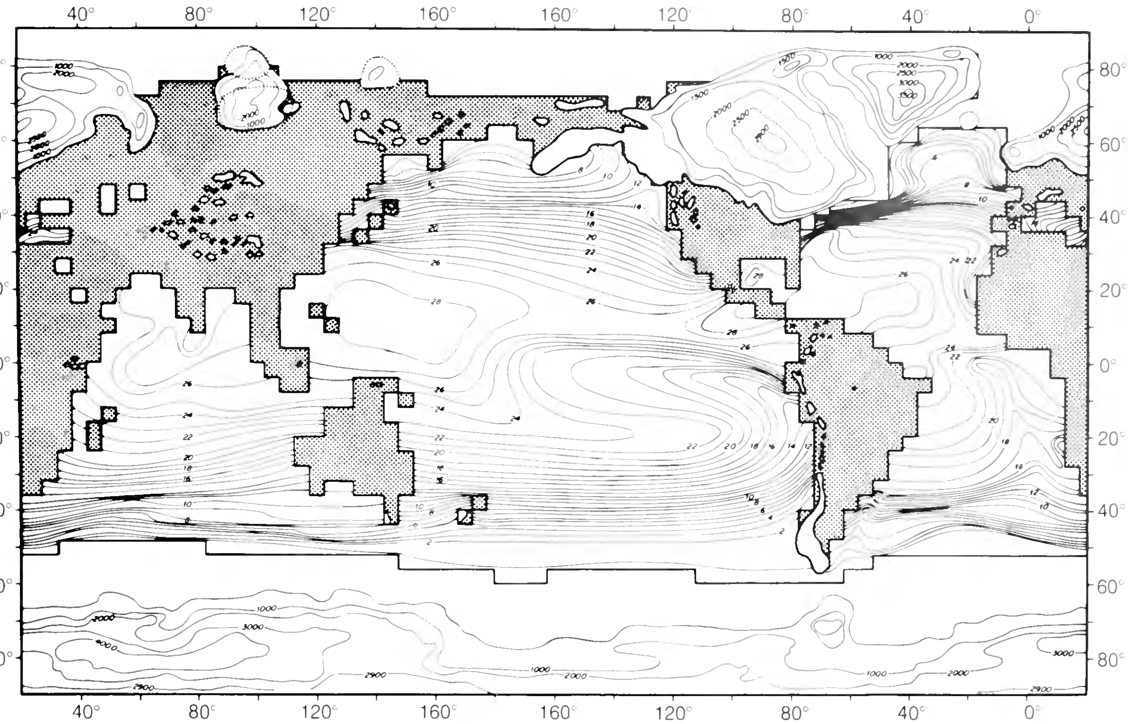


Figure 15. Sea-surface temperatures, ice extent, and ice elevation in the month of August 18,000 years ago.

extremes of sea ice, and 5) the sea-surface temperatures. Four types of fossils (coccoliths, foraminifera, radiolaria, and diatoms), sedimentation rates, and oxygen isotope data were analyzed and compared with present-day conditions.

The data were already on file in the deep-sea core library of the Lamont-Doherty Geological Observatory of Columbia University. The 456 samples that were used to reconstruct the ocean 18,000 years ago were distributed over all ocean areas except the Arctic. The samples documented all major temperature gradients, surficial water masses, and circulation patterns of glacial world oceans.

Global sea-level changes, which are caused by the transfer of water from oceans to ice caps, were calculated by determining the ice volume. Maximum and minimum ice sheet models recorded sea-level changes of 150 to 100 meters. Refinements to these models, using oxygen isotope data, gave an overall value of a drop in sea level of 150 meters.

Sea-surface temperatures were based on quantitative counts of microfossils. The biogeography of living plankton showed that the distribution of individual species and communities tended to conform with the distribution of surface water masses and major current systems. Changes in the distribution of individual microfossil assemblages were interpreted as changes in past oceanographic conditions. Quantitative relationships between the warm (August) and cold (February) sea-surface temperature and the biotic assemblages were established. Development of these methods was one of the investigators' major contributions to the CLIMAP project.

The area covered by permanent ice was substantially different during the glacial maximum from that of today. In the Northern Hemisphere, the presence of huge land-based ice sheets reached approximately 3 kilometers in thickness and the extent of pack ice and marine-based ice sheets significantly increased (see *Oceanus*, Vol. 21, No. 4, p. 65). In the Southern Hemisphere, the most striking contrast was the greater extent of sea ice. Combined with sea level lower by 150 meters, these developments caused substantial changes in surface characteristics of the earth. On land, grasslands, steppes, sandy outwash plains, and deserts spread at the expense of forests; and the extent of snow-covered land increased significantly. Reconstruction of land vegetation was based on pollen distribution and types. These changes, together with the increase in glaciation, caused an increase in surface albedo over modern values.

Another major discovery of CLIMAP was the correlation of the spectrum of global sea-surface temperatures and other land- and sea-based indicators with the variability of the orbital

characteristics of the sun, including periods in excess of 10^5 years. Although a strong correlation has been established between climate variability and solar effects, the search for a mechanism continues.

Assessment

The IDOE projects unquestionably accelerated exploration and study of the ocean basins and their mineral resources in the 1970s. The basic understanding of geologic processes and information about the oceanic crust will be key ingredients in the future exploitation of the ocean basins that may occur in the 1980s, after the legal status of deep-ocean mining ventures is resolved. From a scientific point of view, the projects were extremely successful in that we learned a great deal about the ocean. For the first time, research resources and facilities were made available to study basic questions about the sea floor on a scale and within a time frame necessary to provide the needed answers.

Furthermore, geologists and geophysicists were concerned not only about the traditional questions of mineral resources, but, working with meteorologists, also about the problems of the earth's climate and the processes that control it. Perhaps this broadening of the scientific horizons and the blurring of the boundaries between disciplines will be as important as some of the results themselves.

Those who expected short-term (less than 10 years) results from IDOE projects have been disappointed. We are not mining manganese nodules from the sea floor. And petroleum is not being produced in large quantities from the outer continental shelf or along the upper continental slope. But the primary constraints have been legal and institutional ones. Our scientific understanding far exceeds our ability to solve the legal and institutional problems that confront those who wish to exploit deep-sea resources. And because of the success of the IDOE programs, the basic scientific work will be there ready for use when these institutional questions are finally resolved.

E. M. Davin is Program Manager for the Seabed Assessment Program of the International Decade of Ocean Exploration. M. G. Gross is head of the Decade section within the Ocean Science Division of the National Science Foundation.

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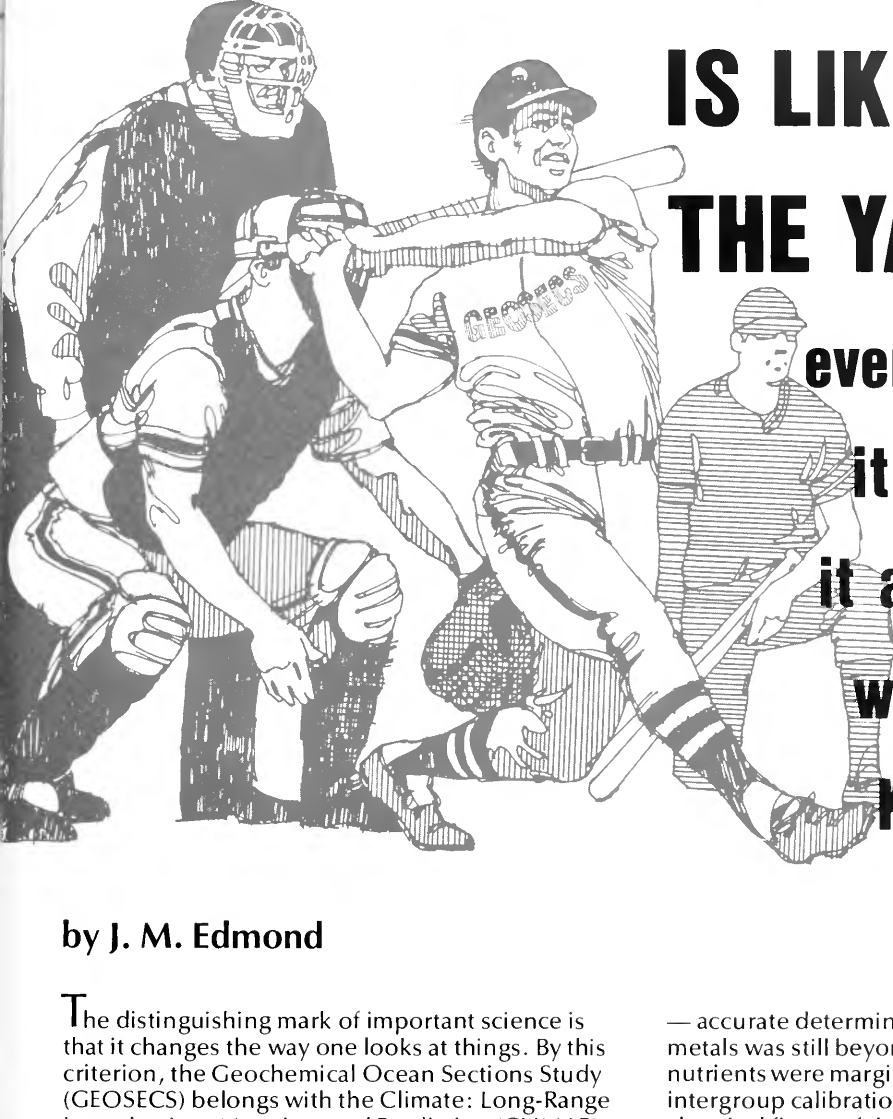
GEOSECS

IS LIKE THE YANKEES: everybody hates it and it always wins . . .

K.K. Turekian (1978)



by J. M. Edmond

The distinguishing mark of important science is that it changes the way one looks at things. By this criterion, the Geochemical Ocean Sections Study (GEOSECS) belongs with the Climate: Long-Range Investigation, Mapping, and Prediction (CLIMAP) study and the Mid-Ocean Dynamics Experiment (MODE) as one of the most important and successful of the International Decade of Ocean Exploration (IDOE) programs and indeed of oceanography as a whole in the 1970s. It was certainly the most amusing.

In the late 1960s, the prevailing ethos in chemical oceanography was that of a handmaiden to marine biology and geology. Although there had been some heroic forays made by geochemists interested in stable and radioisotopes, most work involved measuring nutrients and oxygen. Certainly, these were the only well-measured items — accurate determination of the minor and trace metals was still beyond the state of the art. Data on nutrients were marginal in quality, especially where intergroup calibration was concerned. The chemical fiasco of the International Indian Ocean Expedition was a monument to this situation.* As a consequence, few practicing chemical oceanographers had any real feeling for oceanography: their understanding of the deep circulation and its vagaries was woolly; the central role of organisms in driving much of the chemistry of the water column was not generally appreciated; and the importance of interfacial phenomena went

*Data from different cruises could not be contoured together. Hence the intended division of labor— different areas of the ocean assigned to different groups — led to a data base of little use.

unheeded. There were, of course, a few outstanding exceptions. However, there was no consensus as to what chemical oceanography was all about — a fact that did not seem to create any general unease.

Things were beginning to stir nonetheless. In the mid-1960s Henry Stommel, then of the Massachusetts Institute of Technology, Joseph Reid of Scripps Institution of Oceanography, and Bruce Warren of the Woods Hole Oceanographic Institution (WHOI) found convincing evidence for the existence of a deep western boundary current in the South Pacific. Not only were the chemical data crucial to the identification of this feature and to the delineation of its flow path, but the entire deep Pacific was transformed from a sluggish and featureless abyss to a dynamic entity with a well-developed and complex circulation. Wallace Broecker of the Lamont-Doherty Geological Observatory, using radon and radium because they were relatively easily measured radiotracers in the deep sea, had shown that things were actually happening down there. The discovery by Harmon Craig of Scripps and Brian Clark of McMaster University in Canada of primordial helium in the deep Pacific demonstrated that volcanogenic input, invoked haphazardly by sedimentary geochemists over the years, was a real thing. Craig's systematic investigation (with Devendra Lal of the Physical Research Laboratory at Islamabad, Pakistan) of the uranium daughter isotopes — radium, lead-210, and polonium — was beginning to produce evidence of actual chemistry occurring on very short time scales. Derek Spencer of WHOI and Karl Turekian of Yale University, after much toil, showed that analysis of trace elements and suspended material in the deep water column, still today one of the most difficult areas in marine chemistry, was a practical proposition. Gote Ostlund and Claes Rooth, both of the University of Miami, produced some amazing data for tritium in the Atlantic, indicating the profound results that could be obtained from studying the distribution and transport in the ocean of radioisotopes which had been produced by nuclear bomb tests (see *Oceanus*, Vol. 20, No. 3, p. 53). Behind all this was a burgeoning technology. The capability of both sea-going and laboratory instrumentation was growing rapidly, faster indeed than could be implemented or even funded. The stage was set.

The Grand Design

Overall, GEOSECS was an enormous gamble. Elements and species for which only a few tens of determinations existed were elevated to "core" components of the program with thousands of analyses projected. New and untested sampling techniques were adapted as essential tools. The scale of the operation was to be larger than any in oceanography apart from the Deep Sea Drilling Project (DSDP). It says a great deal about the vision of Stommel, Reid, Craig, Broecker, and Spencer that they could conceive of such an operation, never mind pull it off. The unsung hero, it should be pointed out, was Feenan Jennings, head of the new IDOE program. Without him, it surely would never have come close to success.

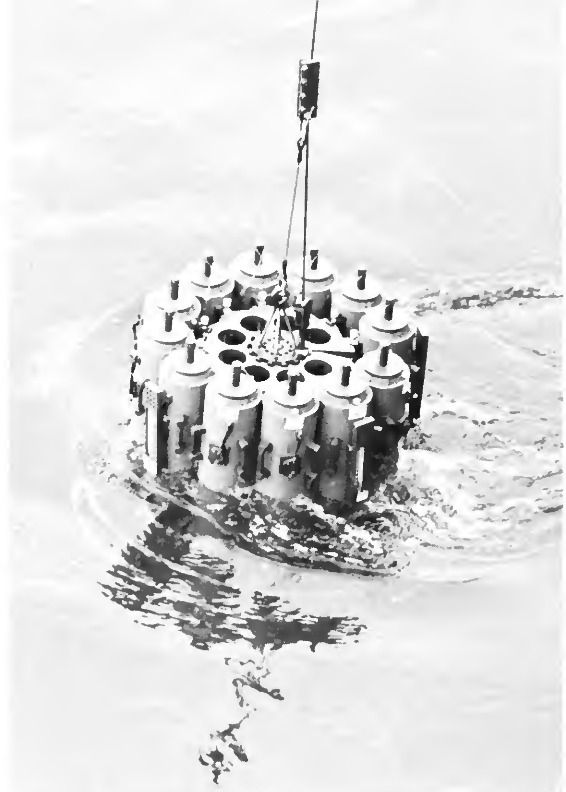
The grand design, simply put, was to map out the deep circulation of the world ocean, to quantify it using a variety of radioisotopes, and within this general framework to establish the major processes that serve to control the water column distributions of a wide variety of elements and compounds and their rates. The primary emphasis was on long, north-south sections through each of the major ocean basins. Upon the shoulders of the late Arnold Bainbridge of Scripps was placed the responsibility of making it all happen. An Operations Group was built up from scratch and a series of test cruises launched.

The occupation of three test stations — off San Diego, Tonga, and Bermuda — was one of the most hilarious escapades in the history of oceanography. Although their ostensible purpose was to establish that various new techniques and systems would actually produce useful information, the reality was more complex. Chemical oceanography was a small, obscure, and difficult field, and, as such, attracted suitably idiosyncratic individuals — individualists to the point of obsession. As baggage, they brought along assorted clones, graduate students, equipment mongers, and some very peculiar ideas about the oceans. The fantails of various ships were transformed into arenas in which the various factions maneuvered and clashed in an atmosphere of perpetual crisis brought on by equipment failure or loss, shattered misconceptions, and near-permanent exhaustion. And it worked. The data generated were of a quality and abundance unprecedented in oceanography. The first test station — GEOSECS I off San Diego — produced beautiful profiles for carbon in all its manifestations — pH, P_{CO_2}, total CO_2, alkalinity, ^{13}C, ^{12}C, and ^{14}C — for radium and radon, tritium and helium–3. The conventional hydrographic data were of the highest quality. Of course, intercalibration caused enormous problems resolved through a seemingly endless series of acrimonious meetings, exchanges of samples and standards, and mollifying tranches of money and equipment to the defeated parties. GEOSECS II carried the campaign to the North Atlantic with similar success. A final odyssey to the southwest Pacific and the show was on the road.

Spencer, Bainbridge, and myself, along with the entire GEOSECS Operations Group, cast off on the research vessel *Knorr* from the WHOI dock on the afternoon of 21 July 1972. There were bands playing, corks popping, and fireworks. For the first

time, the entire system was in place, on one ship, and running. Things got off to a suitably shaky start with the loss of a Conductivity, Temperature, and Depth (CTD) probe at the first station because of badly thought out handling procedures. However, once the round-the-clock operations of the deck and lab crews came up to flank speed, things went relatively smoothly, so that by the first port stop in Reykjavík, Iceland, the great data machine was churning away pretty well as projected.

The early legs were some of the most exciting, as we realized that it really could be done. A major effort had been made to computerize all the shipboard operations. As a result, Bainbridge's group at Scripps was able to issue data reports containing the complete suite of shipboard measurements tabulated and plotted within a few weeks of the termination of each leg. The data were of exemplary quality. Crates of samples began to flood our labs and the major analytical program got underway. The most spectacular results — apart from the beautiful sections generated from the shipboard temperature, salinity, oxygen, nutrient, and carbon dioxide data — were those of helium–3 and carbon–14, of the suspended material, of radium and barium, and of lead–210 and polonium. The tritium data (Figure 1) clearly showed the penetration of sinking water from high latitudes into the deep interior of the North Atlantic, providing for the first time a quantitative estimate of this process, which is central to the ventilation of the ocean. Taken together with carbon–14, carbon dioxide, and radon data it is now possible to calculate, at least roughly, the rate of uptake of fossil fuel CO_2 by the surface ocean and the rate of its penetration into deep waters. The distribution of suspended material and its composition were found to be controlled by a complex interaction between circulation and surface biological productivity. Barium, the first accurately measured trace metal in the oceans, was found to be dominated by its involvement in the biological cycle with a resulting distribution similar to that of the nutrient elements. With its chemical relative radium, it was possible to



A rosette water sampler being lowered by the research vessel Melville *during GEOSECS Indian Ocean cruise in April of 1978. (Photo by Alan Fleer)*

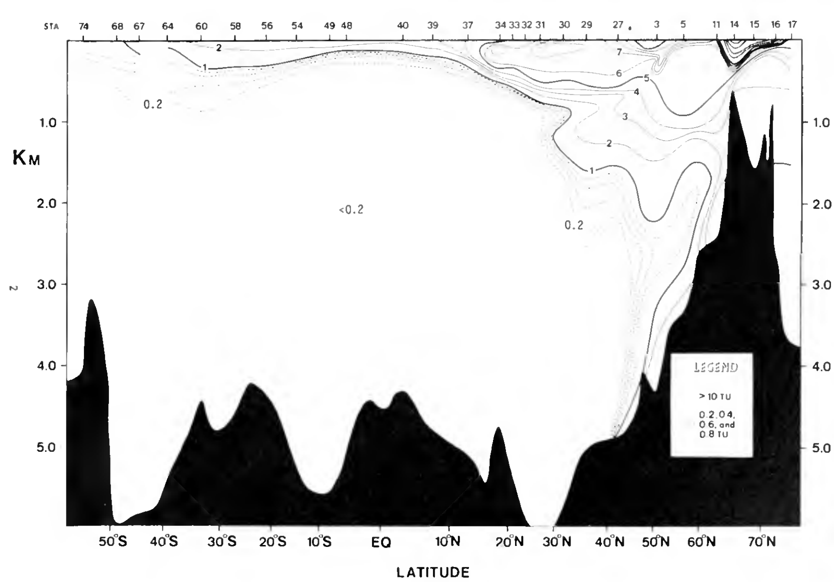


Figure 1. Tritium section of the western Atlantic (1972) from 75 degrees North to 50 degrees South versus depth (km.). Vertical exaggeration is 2,000:1. Horizontal scale is proportional to cruise track.

confirm the extremely rapid circulation times in the Western Atlantic — on the order of 300 years — deduced from carbon–14 data. The chemically reactive radioisotopes of lead and polonium displayed a variety of effects related to the circulation, the size of the particular basin, and the distribution of the suspended material. Much of the intellectual excitement came not from the individual data sets, but from the analysis of an entire suite. At last one could hope to close arguments by an appeal to the behavior of the other species, rather than by guess, hypothesis, or invocation of the deus ex machina.

In a way, however, the Atlantic was a disappointment, especially to those of us interested in discrete chemical processes. The circulation is so rapid that chemistry is obscured by physics. The particular mode of origin of a given water mass — in the Norwegian, Labrador, or Mediterranean seas, or in the Antarctic — gives it a discrete chemical signature in addition to the primary density controlling properties, temperature, and salinity. Hence, the various components of deep circulation could be identified and mapped with a high degree of resolution. However, the processes determining the chemistry itself could barely be resolved. Some of us looked to the Pacific and Indian oceans, where it was expected that the somewhat slower circulation rates would allow fuller development of a purely chemical signal.

GEOSECS soldiered on. In April 1973, the R/V *Knorr* returned to WHOI and the whole battery of equipment was shipped to San Diego; the R/V *Melville* embarked on 22 August 1973, and in 9½ months occupied 147 stations from the Bering to the Ross seas and back. After a three-year pause for regrouping and capital accumulation, the field work was completed with 54 stations in the Indian Ocean, and the Red and Mediterranean seas.

Our expectations were fulfilled. Unlike the Atlantic, where the deep circulation is composed of several water masses injected directly at depth, the Pacific has a single source — the bottom water entering south of New Zealand. This moves north along the western boundary and via several narrow passages floods the bottom of all the basins west of the East Pacific Rise. It is overlain by deep water, which is composed of a mixture of the original bottom water and the intermediate waters above it. It propagates slowly south to be reabsorbed in the Circumpolar Current. A rather similar situation occurs in the Indian Ocean. The residence times for the deep waters are between three and four times longer than in the Atlantic. The effects of chemical processes occurring in the water column and on the sea floor are correspondingly enhanced.

Large-scale models of the ocean are still quite primitive, even for the purely physical processes. Attempts to deal with the chemistry have been rudimentary. Instead, the geochemists have been forced to take a more descriptive approach. One maps the distribution of the various constituents and from this, attempts to deduce the processes that determine the features in the maps themselves. This is an example of data inversion so common in the natural sciences. One's data usually reflect a variety of superimposed processes and are hence a resultant from which one tries to deduce mechanisms.

As an example, let us consider a well-measured profile — Station 202 in the northeast Pacific between San Diego and Hawaii (Figure 2). The temperature decreases smoothly with depth to values characteristic of the bottom water coming from the southwest around Hawaii. The salinity shows a pronounced subsurface minimum. This is the north Pacific intermediate water formed in winter off the Kamchatka Peninsula by deep convection and mixing. Below this, the profile increases smoothly with depth. The plot of salinity versus temperature is linear in this region, suggesting that the water at mid-depth (2 to 4.5 kilometers) is in fact a simple mixture of the intermediate and bottom waters. The oxygen shows a very pronounced minimum (3 percent of the atmospheric saturation value) at about 1 kilometer. This feature has a complex origin, being predominantly advective from the highly productive but slowly circulating region in the northeast Pacific. There is a similar feature in the phosphate and nitrate, reflecting the metabolic regeneration of sinking biogenic debris. The oxygen is "ventilated" by the newer bottom water, the mid-depth region showing an approximately linear increase with depth. The silica and alkalinity profiles increase much more gradually than those of the tissue-related nutrients, phosphate and nitrate. This is a reflection of their much slower rate of regeneration. There is little metabolic advantage in dissolving the opal and calcareous shells of planktonic organisms. Hence, they settle more or less unaffected into the deep interior, probably descending all the way to the sea floor before being completely dissolved.

There is a large advective component in the silica profile. As can be seen from the very pronounced surface depletion, silica is a limiting nutrient for diatoms, radiolaria, and other organisms that have opaline shells. Their productivity is concentrated in regions where upwelling and deep convection bring the nutrient into the surface layer. Such a situation occurs across the entire Pacific north of about 40 degrees North. The sediments there contain opal in abundance and, indeed, dissolved silica increases into the bottom, reflecting the intensity of the dissolution process. This silica-enriched water rides up over the denser incoming bottom water to give the broad mid-depth maximum seen at Station 202 and throughout the mid-latitude Pacific.

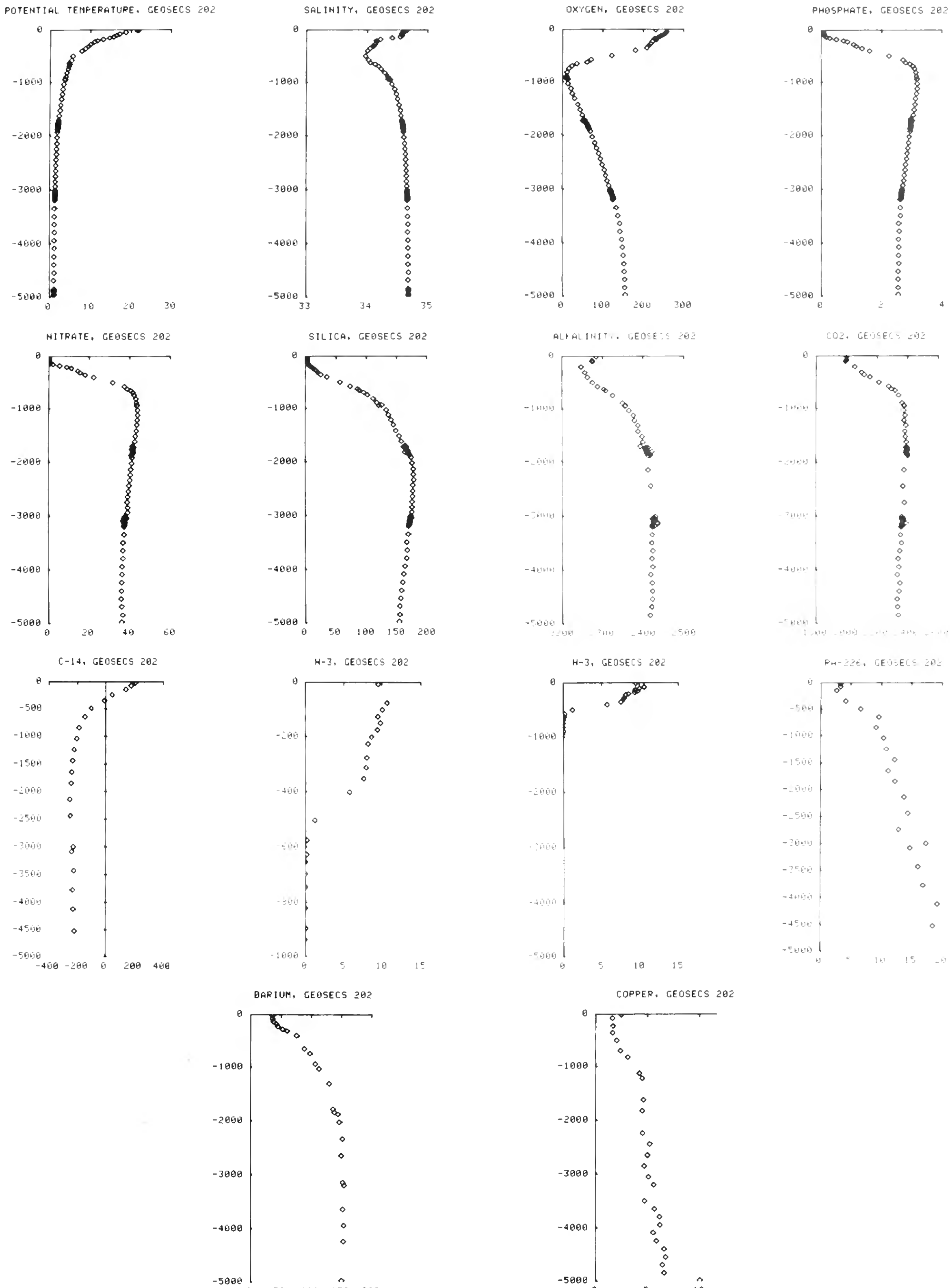


Figure 2. The data set from GEOSECS Station 202 at 139 degrees West between San Diego and Hawaii. Units are: potential temperature (°C); salinity (%); oxygen, phosphate, nitrate, silica, CO_2 (μmol/kg); barium, copper (nmol/kg); Ra-226 (10^{-14} gm/kg); ^3H, TU; and ^{14}C ($\Delta\,^0/_{00}$).

The alkalinity profile, a measure of the dissolved carbonate, is more complex. It is far from being a limiting nutrient. Much of its variation is determined by the same processes of evaporation, precipitation, and freezing important for total salt. It is "quasi-conservative." The "specific alkalinity" (the alkalinity divided by salinity) gives a closer reflection of the chemical variations. These are very similar to silica.

The carbon dioxide profile can be regarded as a composite of that for alkalinity — as carbonate — and that for the nutrients, for example, organic carbon. Thus it increases steeply in the upper waters, as do phosphate and nitrate, but has a very broad maximum in the deep waters, like silicate and specific alkalinity.

The radiocarbon profile shows a very high surface maximum and a steep drop-off to a minimum in the deep water. Below about 3 kilometers, it increases gradually to the bottom. The high surface values are derived from carbon–14 produced by nuclear bomb tests. This is mixing and advecting slowly into the interior, and by 1973 had penetrated only a few hundred meters. The minimum reflects the oldest water, in terms of isolation from the surface. The somewhat higher bottom values identify the incoming water from the southwest.

Natural radiocarbon is produced by nuclear reactions caused by cosmic ray impingement on the upper atmosphere. The nuclear bomb tests approximately doubled the global inventory of carbon–14. This bomb carbon acts as a dye, tracing vertical and horizontal water movements from the surface into the interior of the ocean. Tritium, the radioactive isotope of hydrogen, also is produced by cosmic ray reactions: however, the bomb contribution has been relatively much greater than for radiocarbon. The tritium half-life of 12 years is shorter than the time scales of all but the most vigorous physical processes in the oceans. Thus, the natural isotope has decayed to undetectable levels below the main thermocline* everywhere in the ocean. This is seen strikingly at Station 202. The surface levels are high, reflecting advection from the north — the main site of injection. The values decrease sharply to zero between 400 and 600 meters. Again, nuclear bomb-produced tritium acts as a tracer for vertical and horizontal processes in the upper water, but on a projected time scale of tens of years rather than hundreds as for radiocarbon.

Another potentially useful tracer is radium (Ra-226). This isotope has a 1,600 year half-life and is produced in the sediments by decay of thorium–230. Thus, it is injected at the bottom of the ocean rather than at the top. The profile from Station 202 reflects this: it increases steadily from the base of the thermocline to the sea floor. However, the large drop in concentration in the upper kilometer cannot be interpreted as reflecting decay of radium during slow vertical mixing to the surface. The times required — thousands of years — are much too long and grossly contradict the radiocarbon and tritium data. In fact, as can be seen from the distribution of its chemical daughter barium, radium is involved in the biological cycle — for reasons that are not clear.

Barium has been measured on many GEOSECS stations because of interest in both its trace element geochemistry and its relationship to the radiotracer radium. As the program progressed, techniques were developed to measure several other metals that occur at very low concentration levels in the ocean. Unfortunately, most of these behave very similarly to the nutrients regardless of whether they are "essential elements" or not! Thus, they have not yielded any especially unique insight into chemical processes in the deep ocean. An exception is copper. Its profile at Station 202 shows a pronounced similarity to that of radium. At the surface, the values are low; they increase steeply through the main thermocline, and then gently to the sea floor. By analogy with radium, one can explain this distribution as being controlled by a strong bottom source with scavenging and removal by particulates — the equivalent of radioactive decay — occurring at mid-depth and active uptake by organisms occurring in the shallow water. The predicted bottom source has been confirmed by numerous subsequent studies of copper in the pore water of deep-sea sediments. Less is known about the water column processes. Apparently, the scavenging agent loses its binding capacity upon incorporation into sediments — the copper being released to the water column.

The radioactive decay daughter of radium — the isotope lead–210 — shows rather similar behavior to copper in the water column as does its daughter polonium–210. Both are actively scavenged. However, because of their chemistries they are permanently incorporated in the sediments: thus their profiles generally decrease in concentration with depth.

So far we have looked at things in one dimension. Space and the present status of the data and of our understanding do not allow us to pursue the discussion to consideration of a complete three- (or four-) dimensional picture. However, this is the long-term aim of the program: to map the distribution of chemical tracers in the ocean and to quantify the time scales of the controlling processes using the radioisotopes. A single example of the first objective must suffice. The distribution of silica on a north-south section in the western Indian Ocean is shown in Figure 3. The bottom water, relatively low in silica, is moving north from the

*A vertical temperature gradient in a layer of water appreciably greater than the gradients above and below it.

Circumpolar Current. In the Arabian Sea, large amounts of silica are added because of the diatom flux from the upwelling regions at the surface. Vertical mixing also takes place and the resulting water mass — the Indian Ocean Deep Water — labeled with silica, moves south as a lobate tongue on top of the incoming bottom water. Other than in the Arabian Sea, it is not clear that the silica distribution is affected by anything apart from advection and mixing. Work on this section will allow us to estimate not only the silica fluxes, but also the rates of the physical processes.

Now, "Son of GEOSECS" — the Transient Tracers Program — is getting under way. It aims at the intensive exploitation of the radiocarbon and tritium distributions outlined by GEOSECS as tracers of physical processes in the ocean. Although some of the "old reliables" are involved, many of the rest of us, having more or less completed the enormous analytical program, are grappling with the resulting data set in an effort to quantify the rates and mechanisms of the processes that control the chemistry of the oceans.

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The most recent collection of GEOSECS results was published as a series of papers in Earth and Planetary Science Letters, Vol. 32, 1976.

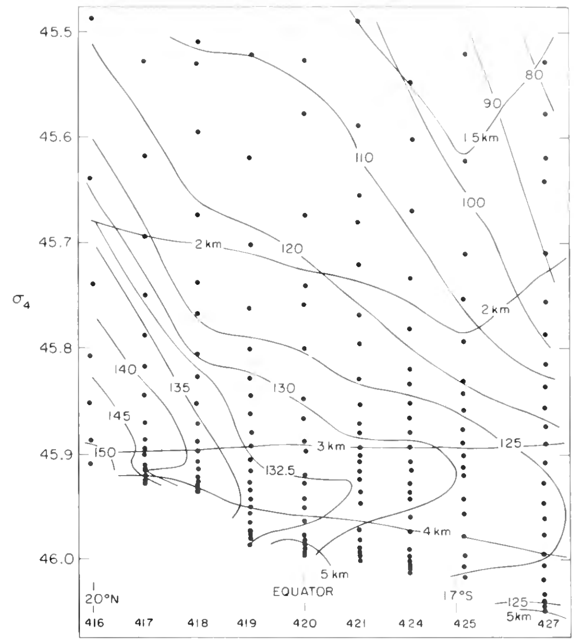

Figure 3. The GEOSECS section of silica in the western Indian Ocean, plotted against σ_4, the density anomaly for the samples when moved adiabatically to 4-kilometer water depth.

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A New Dimension in Physical

by Allan R. Robinson and William Simmons

Physical oceanography is a sophisticated modern science. In recent years, new and challenging problems in the physics of the sea have begun to emerge and be defined. Many of these problems require a scale and scope of effort far beyond any previously practiced. This new, large, and vital dimension to the science has been provided by the International Decade of Ocean Exploration (IDOE), which was supported primarily by the National Science Foundation and the U.S. Navy's Office of Naval Research.

Only a few decades ago, the mysteries of the vast uncharted seas stirred the imagination of only a few bold naturalists and explorers. Now, shared by a diverse group of scientists and technicians, these mysteries are being unraveled. Traditionally, physical oceanographers collected samples of seawater from bottles attached to a wire hung over the side of a ship, and then mapped the distribution of properties. The contemporary observer at sea is likely to be working with complex electronic gear and a shipboard computer, and to have colleagues who include land-based mathematicians and instrumental engineers. Data collected from ships are often pooled with measurements obtained from arrays of instruments arranged to move about freely with the deep currents themselves, from networks of moorings anchored to the sea bottom unattended for more than a year, or from satellites. Data sets are analyzed by new, powerful methods that perhaps originated in other fields, such as astronomy or seismology. They may then be fed into a theoretical model that is running on one of the largest, fastest computers in the world, and that rivals in complexity the meteorologists' numerical models for global weather prediction.

Physical oceanographers want to describe accurately how the water moves about throughout the ocean and what its physical characteristics are. What are the patterns of currents and waves; what were they in the past; what will they be like in the future? What are the associated distributions, for example, of temperature and salinity? They also want to understand these motions in terms of basic physical principles — that is, according to the general laws of the dynamics and thermodynamics of fluids — and to model them. Why is there a Gulf Stream? What causes waves to break? When, where, and how are energy, heat, and momentum put into the sea? How are these quantities moved about from place to place and depth to depth and ultimately lost?

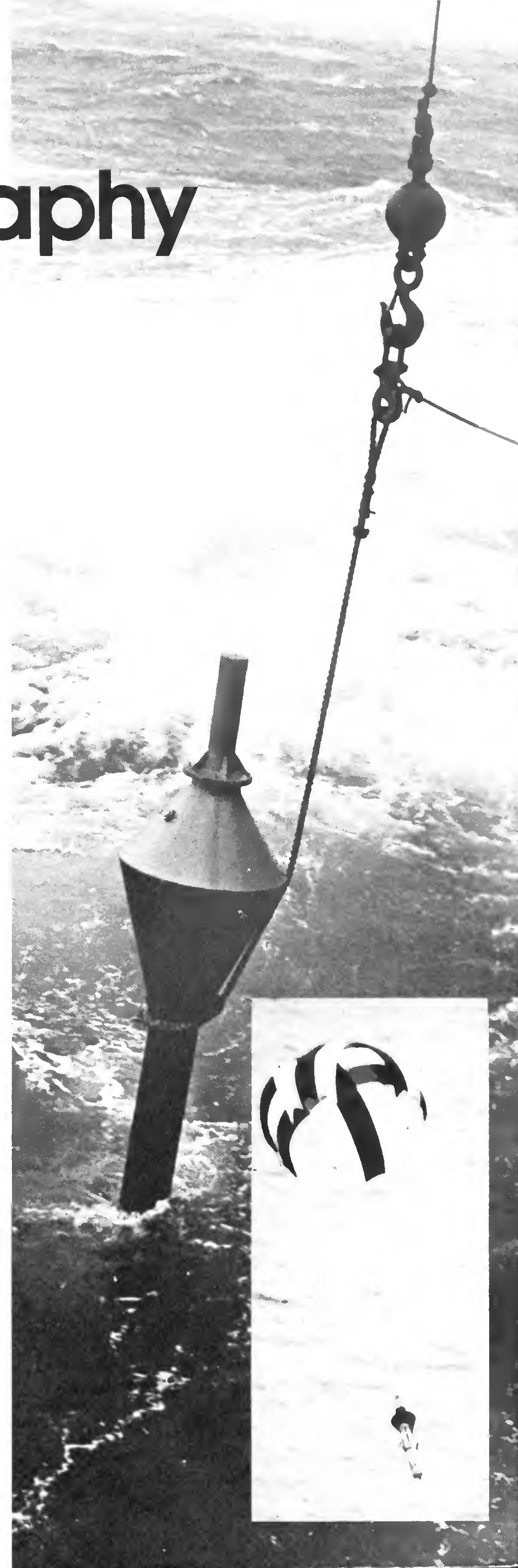
The very large size of the oceans makes it difficult to get answers to these questions. Man is small, his resources limited, and his technology relatively primitive compared to what is needed. Moreover, large-scale fluid flows are almost always turbulent — that is, of an erratic and irregular nature — and the ocean is no exception. A wealth of physical phenomena occur in the ocean, characterized by a variety of time and space scales ranging from seconds to longer than millennia, and from millimeters to the circumference of the earth itself. For example, some scales are directly imposed by ice ages, or seasonal or daily heating and cooling of the sea surface, or the size of an ocean basin, or the extent of submarine mountain ranges. Other scales arise spontaneously from internal resonances or turbulence. Eddy currents or turbulent elements hundreds of kilometers in extent are now known to often dominate the flow.

The sea is not an isolated physical system. Its motions are affected by the shape of its irregular container formed by the continental coasts and the topography of the sea bottom and also by fluxes of heat, particles, and material through and along these boundaries. But predominantly, the ocean interacts vigorously with the atmosphere. Physical

Oceanography

oceanography and atmospheric physics (meteorology) cannot be separated. The motion of the air above and the water below the air-sea interface is governed by exchanges of heat and energy across that interface. These exchanges themselves depend on the constantly changing, never quite repetitive patterns of winds and currents. The problem of understanding the circulation of the ocean and the atmosphere must be approached in terms of the coupled system of two fluids with active, but poorly understood, feedback mechanisms operating across their mutual boundary. Until very recently, our understanding of ocean currents and temperatures was too sparse to allow this approach to be taken by scientists. But oceanographers and meteorologists have been able to initiate feasible research on how the ocean and atmosphere together determine the ever-changing weather and climate of the earth. Because of its massive mechanical and thermal inertia, the ocean is believed to be particularly important for events that take months or years to occur. The sea responds to storms and weather patterns and contributes to climatic changes that occur over land and the oceans.

Physical oceanography is not easily isolated as a scientific activity. As the water moves about, it carries along or pushes around dissolved matter and particles, including chemicals, nutrients, tiny plants and animals, and material destined for deep seabed sediments. Important problems in other ocean sciences — biology, chemistry, and geology — are shared by physical oceanographers. They deal with fundamental questions, such as the origin and history of the oceans, the detailed chemical makeup of seawater, the structure and function of complex ecological systems, the distribution of species, and aspects of evolutionary theory and genetics. Even before World War II, when oceanography was emerging as a recognized science in the United States, it was realized that many important research questions were interdisciplinary, with a need for substantial input



Instrumentation used by physical oceanographers. At right, a free floating drifting buoy is being launched from a research vessel. The buoy will follow the surface current and transmit data on seawater temperature and atmospheric pressure to an orbiting satellite. Inset shows deployment of similar buoy by air. Facing page, the R/V Chain *working with "hardhat" moorings. The barrel-like plastic enclosures house glass spheres that allow electronic instruments to be moored vertically in the water column at great depths, recording current direction and speed for more than a year.*

from physical oceanography. But decades were required to achieve sufficient knowledge of some of the component pieces, thereby allowing a potentially successful scientific attack across the scientific fronts. Today we are at the threshold of a truly interdisciplinary era in ocean science. Practical problems — in fisheries, navigation, underwater sound propagation, military operations, underwater mineral resource development and exploitation, environmental management, and chemical and nuclear waste disposal — are now being addressed realistically.

Thus physical oceanography is a science that deals with a complex wealth of phenomena. And the field is changing rapidly as a result of an increase in activity. It is an interactive and interconnective science that is moving forward into exciting joint research efforts with meteorologists, biologists, geochemists, environmental engineers, and others. Progress has been rapid and much has been learned, including how little we really know and how long it will take to identify, quantify, and model physical phenomena adequately in the sea. The physical oceanographer of 1980 is probably more modest about his understanding of the sea than was his counterpart in 1950. Nonetheless, no decade has taught us more than the 1970s. This was largely the result of the new dimension added by the International Decade of Ocean Exploration, which allowed a timely and concerted attack on selected phenomena, large in scale and scope, an effort never before possible but one that was required for development of the science.

Programs and Accomplishments

Six IDOE programs — the North Pacific Experiment (NORPAX), the Mid-Ocean Dynamics Experiment (MODE and POLYMODE), the International Southern Ocean Studies (ISOS), the Coastal Upwelling Ecosystem Analysis (CUEA), the Geochemical Ocean Sections Study (GEOSECS), and the Climate: Long-Range Investigation, Mapping, and Prediction (CLIMAP) project — relate directly to physical oceanographic goals. Their scientific objectives vary widely, as do their locations, strategies, instruments, models, and results. Three of them — NORPAX, MODE/POLYMODE, and ISOS — were essentially physical. CUEA was jointly physical and biological, while GEOSECS and CLIMAP were primarily in other disciplines, but had important ramifications for physical oceanography. Each was planned and executed by a relatively large group of scientists and engineers. They came from many institutions, and had widely varying but complementary interests, and they worked together with initiative and independence on scales and at levels of cooperation not seen before in ocean science. These were the unifying characteristics of IDOE programs. We will briefly review the principal objectives and preliminary results of four of these six programs, the GEOSECS and CLIMAP programs having been covered elsewhere in this issue (see pages 33 and 30, respectively).

I. NORPAX was concerned with large-scale ocean atmospheric interactions. Compared to the atmosphere, the ocean has a tremendous capacity to store heat and energy, but it also has tremendous inertia and a potential for delayed feedback on climatic time scales. Working in the northern and equatorial Pacific (Figure 1a), NORPAX scientists were able to document the existence of enormous pools of surface water anomalously warmer or cooler than the mean by 1 to 1.5 degrees Celsius. These pools can be up to 300 meters deep, 1,500 kilometers in lateral extent, and 2.5 years in duration.

Using computer models and numerical techniques, NORPAX scientists have been able to successfully forecast the shapes and intensities of anomaly patterns up to a season in advance (Figure 1c). These are useful in illuminating upper ocean processes, and also for forecasting long-term ocean effects on the marine atmosphere. Such atmospheric forecasts (Figure 1e), and also longer-term climatic scale forecasts of the effects of the ocean-modified atmosphere over the American land mass have been successfully developed by NORPAX scientists. The potential applicability of this work to the practical problems of mankind is profound.

El Niño is the name given to dramatic warming events of the surface waters off the coast of Peru, previously thought to be a local effect. But NORPAX scientists have uncovered a reliable predictor for El Niño events through tide gauge records from near-equatorial islands (Figure 1a). Several months prior to an El Niño event, mean sea level drops markedly in the eastern Pacific and rises correspondingly in the western Pacific (Figure 1b) — striking evidence for the global nature of the longer-term patterns of variability. The change is associated with a failure in the equatorial trade winds, and promising schemes to account for the transoceanic mass transport from west to east have been proposed (Figure 1d).

By virtue of its close relationship to climatic processes, much of NORPAX is likely to be continued into the 1980s and, perhaps, beyond, as part of the World Climate Program, a major international scientific undertaking being set up by the United Nations and the International Council of Scientific Unions.

II. Wherever closely spaced measurements are made in the ocean, eddies are found. But such measurements are rather new. The traditional view of the ocean is that of a mostly quiescent flow with isolated regions of intense currents, such as the Gulf Stream. This viewpoint is depicted in Figure 2d, which is based on the average of all data that happened to be available before 1953. Contrast that picture with the almost synoptic post-IDOE view of the same region (Figure 2a), showing a convoluted Gulf Stream, with Gulf Stream-spawned isolated

rings of current both north and south of the stream. But rings are only part of the new variability picture. Scientists in the MODE and POLYMODE programs, using quasi-synoptic multiple-ship surveys, supplemented by arrays of moored, drifting, and profiling instruments, uncovered intense mid-ocean eddy fields (Figure 2a [I, II, III]). Thus the composite post-IDOE picture is a good deal more complicated. Mesoscale variabilities from ten to hundreds of kilometers in extent and a few days to months in duration are seen to distort the thermal structure over the entire region, through vertical excursions from fifty to several hundred meters and at all depths. Charts of this kind are significant products of MODE and POLYMODE, the latter a joint U.S.-Soviet experiment. Only an IDOE-level effort could have produced them.

Besides the MODE-like eddies shown in Figure 2a, POLYMODE also uncovered intense variabilities of smaller (about 20 kilometers) and larger (over several hundred kilometers) scales. Very long-term moorings suggest the existence of variability scales up to years in duration and perhaps thousands of kilometers in extent. Our view of the variety of mid-ocean variability has been considerably expanded.

Eddies have an important effect on the average general circulation. In POLYMODE, special efforts were made to explore average eddy intensities geographically through widely spaced mooring clusters. Out present view of the distribution of deep eddy intensity in the North Atlantic is shown in Figure 2b. Based on NORPAX data, a similar picture could be pieced together for the western North Pacific, and historical data can now be reinterpreted to support eddy variability almost everywhere in the world oceans.

Modeling of the large-scale circulation, including for the first time all the known varieties of mesoscale variabilities, reached a new level of sophistication and believability during the IDOE. Model flows of one or more gyres have been constructed that are realistic in many aspects — including meandering and separating boundary currents, warm and cold rings, and eddies — and that parallel the real ocean in scale, intensity, structure, and distribution. Examples are shown in Figure 2c. These will form the basis for new post-IDOE directions in ocean research.

III. By virtue of its size, its interconnections with the three principal mid-latitude ocean basins, the intensity of its forcing, and the diversity of its phenomena, the Southern Ocean has long been a region of major interest to physical oceanographers. Despite its hostility and inaccessibility, much was known about the Southern Ocean prior to the IDOE. The idea that surface cooling at high latitudes led to the formation of denser water that could sink along isopycnal surfaces to form the intermediate and deep waters at lower latitudes was well established (Figure 3a), with provision for certain zonal variabilities. But the actual processes of the water formation and sinking were unclear. Even the magnitude of the transport of the Circumpolar Current was uncertain. An IDOE-level effort was called for, but one essential element was missing: the technological development of moored and bottom-mounted instruments capable of surviving an Antarctic winter in situ. This was accomplished in the early 1970s, when ISOS was organized within the IDOE.

Early results of ISOS hydrographic surveys and moored current-meter arrays in Drake Passage have established the Circumpolar transport at 120 ± 20 million cubic meters per second to the east. Because of this large transport and other characteristics, it is a current that is now known to be comparable to the Gulf Stream. Surprisingly, the post-IDOE Circumpolar Current is not a single intense current like the Gulf Stream, but rather, three distinct current jets separating four distinct, more quiescent water mass types (Figure 3b). Outside the passage, south of the eastern Indian Ocean, the mean meridional thermal structure (Figure 3c) is reminiscent of that of the Gulf Stream (Figure 3d), including a lens of nearly uniform temperature water (a thermostad) of 13 degrees Celsius.

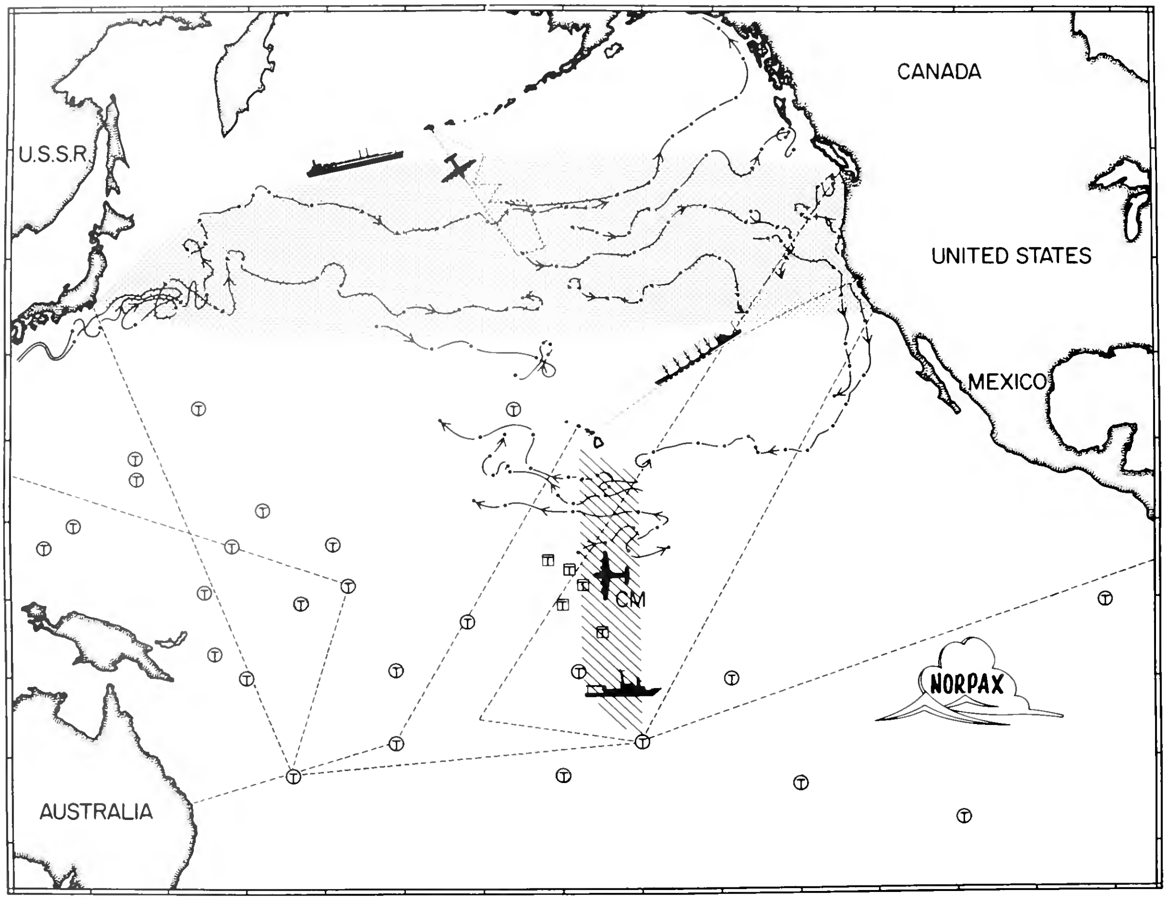
The Circumpolar Current was discovered to form rings, like the Gulf Stream (Figure 3d at 36 degrees West). By chance, ISOS scientists happened on a Polar Front ring during formation and were able to document the complete formation process (Figure 3e).

Mesoscale eddies also were found near the Circumpolar Current in ISOS and were shown to play an important role in the cross-stream global poleward heat balance. This was a major contribution to eddy science.

Modern modeling of the Antarctic current systems also has been initiated in the IDOE, with eddy resolving general circulation models analogous to those appropriate for mid-latitudes. Examples of current models are shown in Figure 3f.

IV. CUEA was motivated by interest in the coastal upwelling process, and by interest in the intense biological processes (see page 52) that result from nutrient enrichment caused by upwelling. At the outset, CUEA scientists realized that a broad scope was needed and included coastal processes in general, biology, and geochemistry. They soon established conclusively that coastal upwelling is a rapid response, intermittent process. At three sites — off Oregon, Peru, and the northwest coast of Africa — cold, nutrient-rich waters were seen to flood the sea's surface in less than one day after the onset of favorable wind conditions, and to be continuously replenished as long as favorable winds persisted. Such favorable events occur every three to ten days, depending on local surface weather patterns. Miraculously, phytoplankton and zooplankton in these regions have life cycles of two to seven days, respectively, so that primary productivity also occurs in turbulent

The North Pacific Experiment



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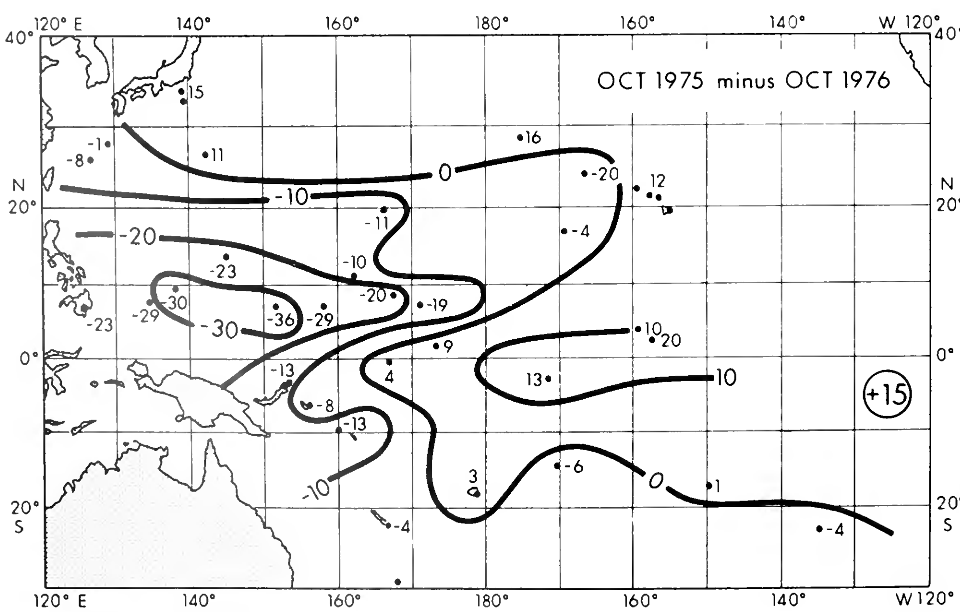

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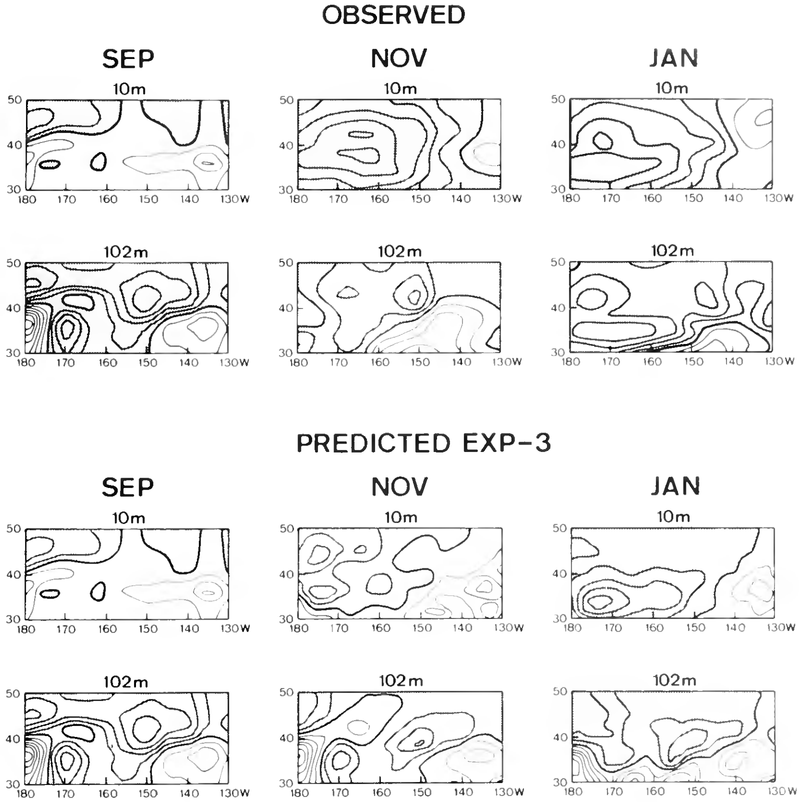

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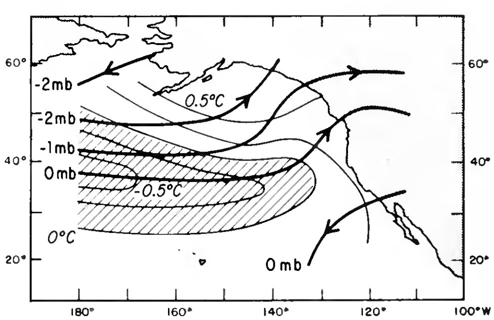
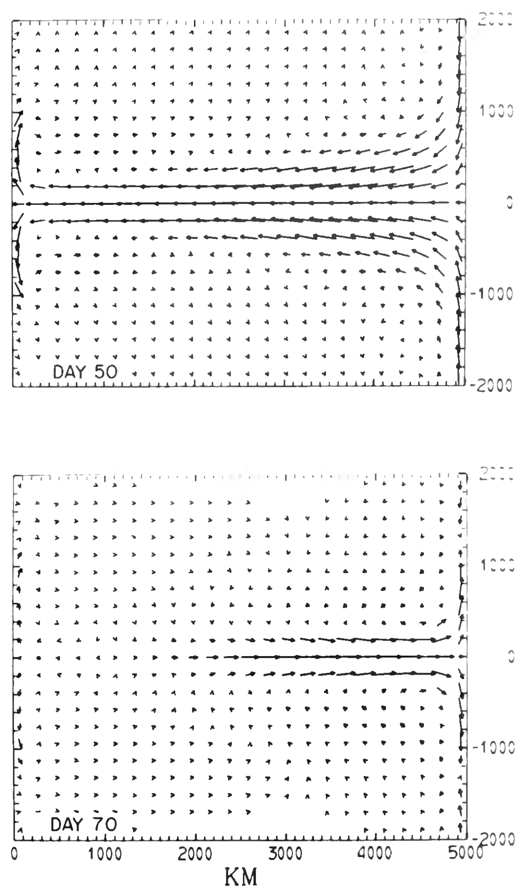




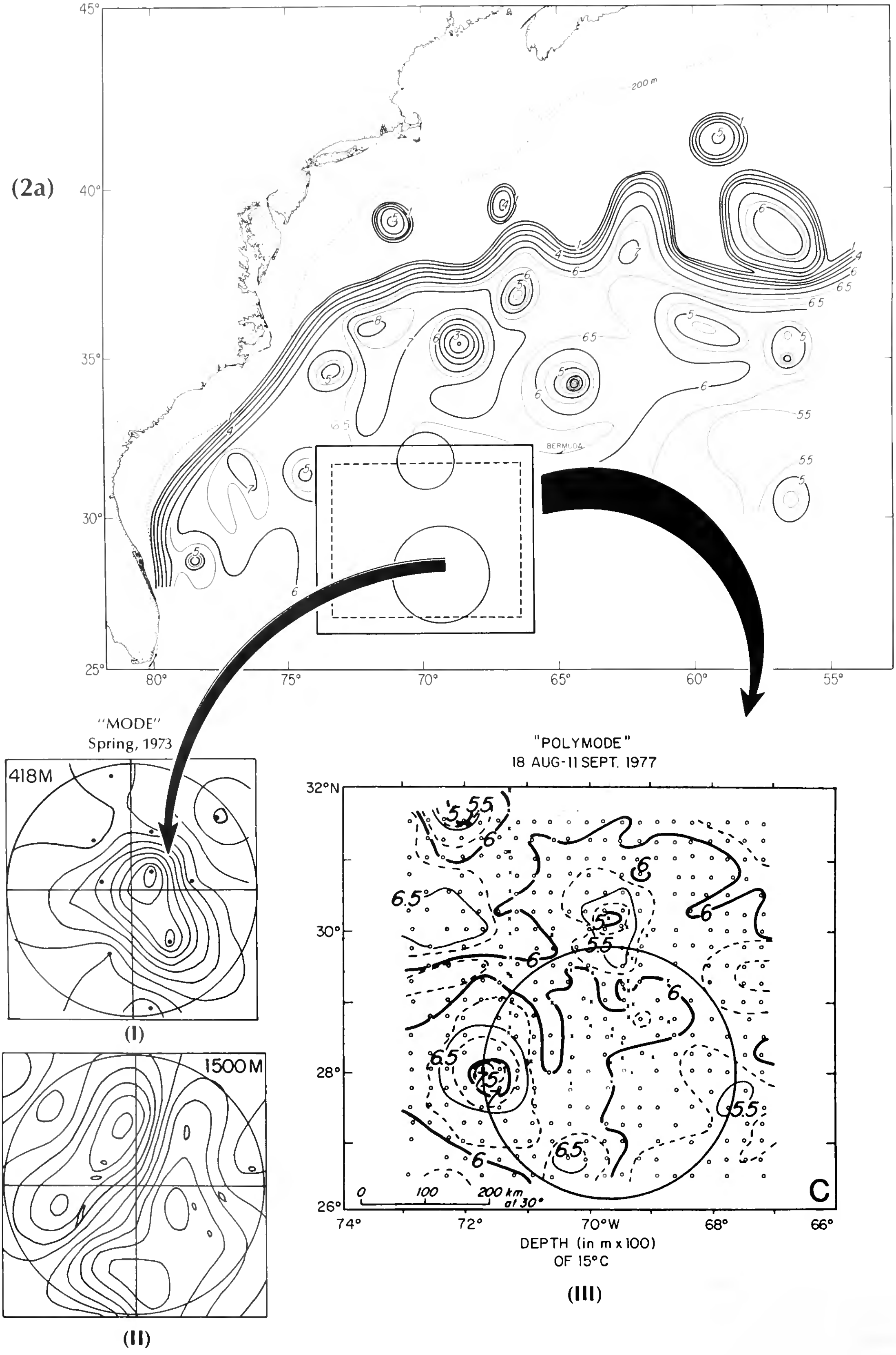
(1d)

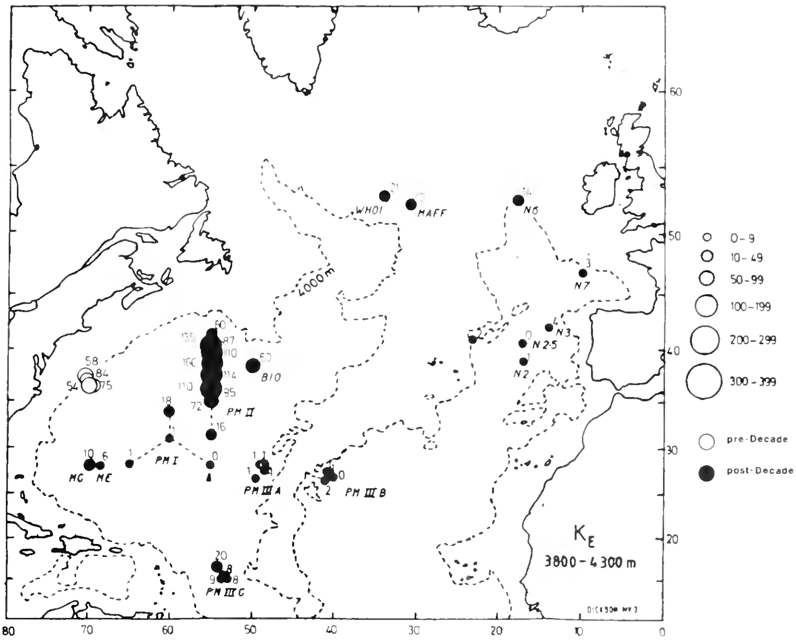
NORPAX

Figure 1. Selected results of the North Pacific Experiment (NORPAX). (1a) NORPAX observation systems. The ship of opportunity XBT area is stippled; equatorial drifting buoys tracks are dashed lines; Ts represent tide gauges; and aircraft and research ships operating between Hawaii and Tahiti are hatched. (1b) The change of sea-surface topography (cm) from October 1975 to October 1976. Circled number at right is the sea-level change at the South American coast (after Wyrtki, 1979). (1c) Observed and model evolution of anomalous temperatures at 10 and 102 meters in 1976. Contour intervals are 0.5 degree Celsius at 10 meters and 0.2 degree Celsius at 102 meters. Negative anomalies are shaded (after Haney and others, 1978). (1d) Upper layer velocity vectors. The equator is at 0. Day 50 shows the initial state when model "trade" winds are first diminished. Twenty days later, the equatorial and coastal currents have reversed, sending warm surface waters to the eastern shoreline (Hurlburt and others, 1976). (1e) Estimated winter sea-level pressure from October sea-surface temperature (SST) data. SST pattern is a cool (shaded) anomaly along 35 degrees North. Estimated pressures give strong westerly winds along 40 degrees North (Davis, 1978).

The Mid-Ocean Dynamics Experiment

(2a)



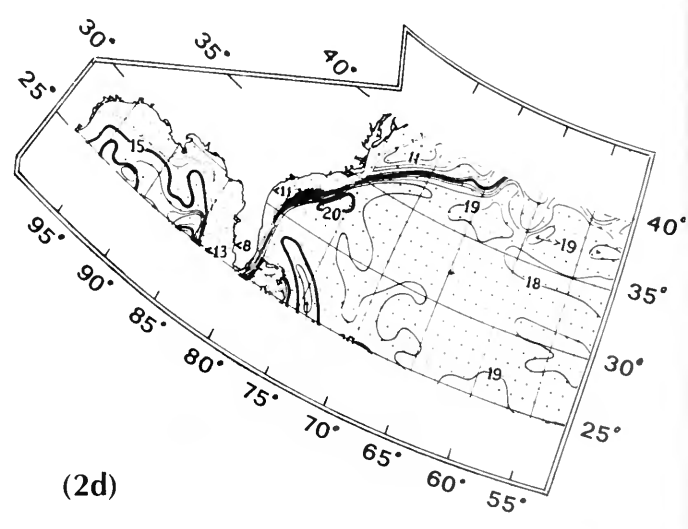


(2b)

MODE/POLYMODE

Figure 2. Selected MODE/POLYMODE pre- and post-Decade conceptions. (2a) Lines of constant depth along the 15-degree Celsius isotherm based on XBT, CTD, hydrographic, and satellite infrared data from March to July 1975. Since current flows along these lines, they show the Gulf Stream, and nine cyclonic and three anticyclonic rings. Note the new ring forming near 57°W, 39°N (Richardson and others, 1978). The insets are typical synoptic eddy maps: (I) is an internal ocean "weather map" in the thermocline obtained during MODE-1, an experiment carried out for several months; (II) is in deep water. Currents flow along the contours. Speeds are greater when contours are bunched together (courtesy of J. McWilliams). The diagram (III) is a thermocline eddy weather map from POLYMODE. Dots are XBT stations. These maps were obtained in the extended (square) region for more than a year (POLYMODE XBT Group, 1978). (2b) Location and average intensity of the eddy currents (eddy kinetic energy) at all points in the North Atlantic deep water where it is known from direct measurement. Note that almost all knowledge was obtained during the Decade (courtesy of R. R. Dickson). (2c) Thermocline and deep water current maps from a computer general circulation model of a North Atlantic-like double gyre (Holland, in the MODE Group, 1978). The southern (or lower) half of each map corresponds to the North Atlantic, the Gulf Stream, and Sargasso Sea region. Compare those to the currents and eddies in Figure 2a. The model at far right is an average taken from several years of eddy studies. Intensities should relate to the measurements in Figure 2b. (2d) Average temperature in degrees Celsius based on all hydrographic and MBT data available prior to 1953 (Fuglister, 1953).

(2c)



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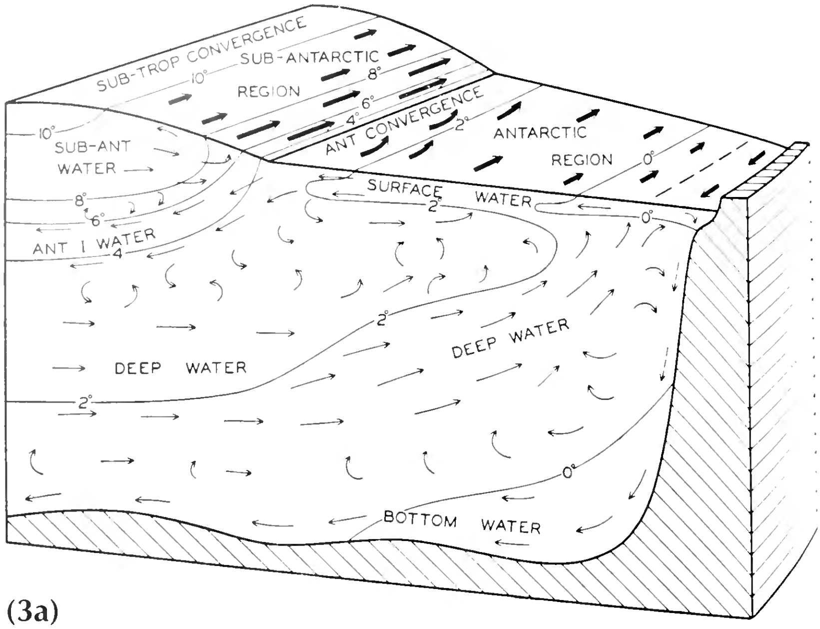
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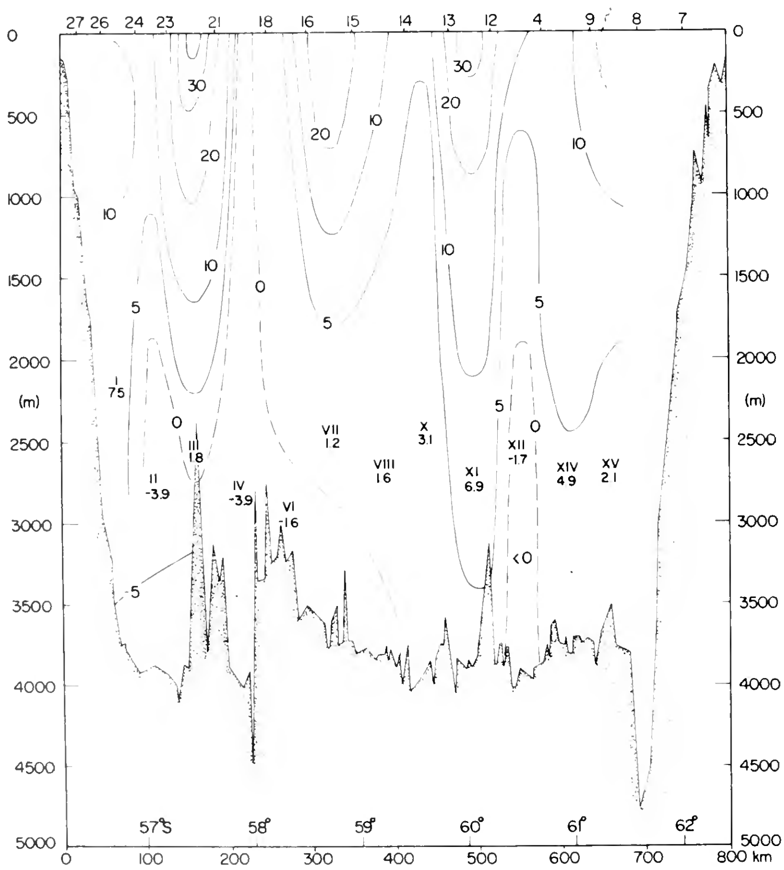
(3a)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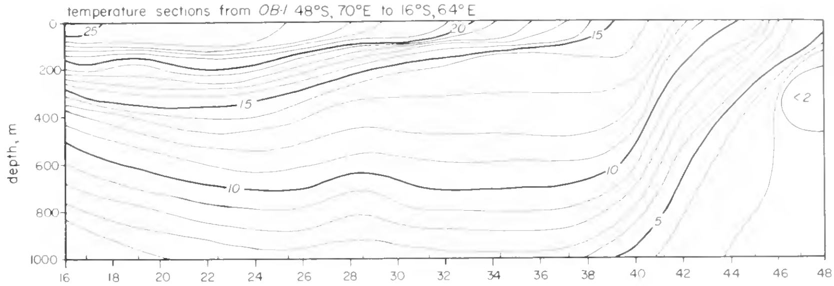

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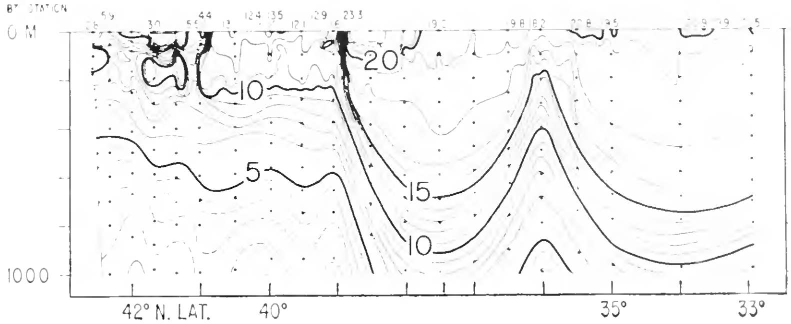

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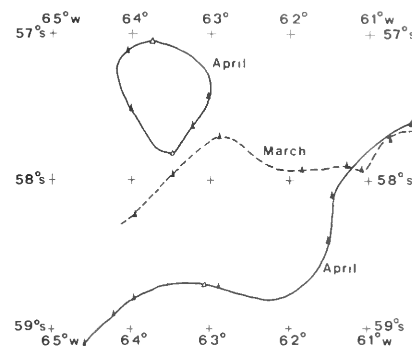
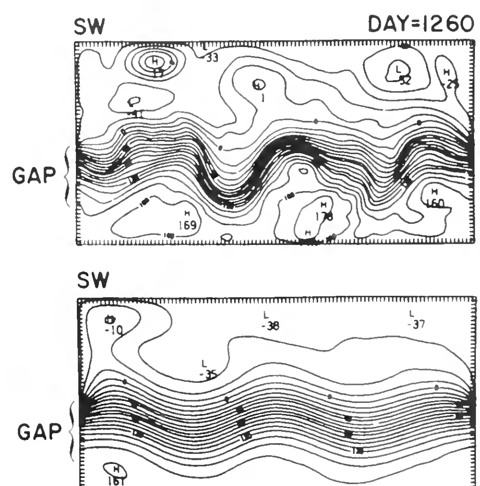


(3e)

ISOS

Figure 3. A pre- and post-Decade look at selected data from the International Southern Ocean Studies (ISOS). (3a) Traditional Antarctic thermohaline circulation (Sverdrup, Johnson, and Fleming, 1942). (3b) Three jet structure of the Circumpolar Current from direct measurements across Drake Passage (Nowlin and others, 1977). (3c) Meridional temperature section from Antarctic to south equatorial current in Indian Ocean in degrees Celsius (McCartney, 1977). The current is the slope up to the right; the thermostad is at about 13 degrees Celsius. No ring appears here (but see Figure 3e). (3d) Temperature section across the Gulf Stream along 64.5 degrees West in degrees Celsius (Fuglister, 1963). The current is the slope up to the left (near 39 degrees West Longitude) and the thermostad is at 18 degrees Celsius. A ring (at 36 degrees West) is also present. (3e) Evolution of a Circumpolar Current ring in 1976. Contour is edge of Polar Front (Joyce and Patterson, 1977). (3f) Eddy maps and smooth average circulation from computer model set up to simulate the Antarctic. GAP is the model's Drake Passage (McWilliams and others, 1978).



(3f)

bursts following the cycles of the weather. This is a major new discovery.

Together with the offshore upwelling flow is an alongshore current quite close to the shoreline. However, its signal and the upwelling signal itself can be masked by much stronger flows associated with coastally trapped waves generated perhaps many hundreds of kilometers away and totally unrelated to the local wind-forcing events. Alongshore scales are typically several hundreds of kilometers. The recognition and identification of these two separate effects, locally and remotely generated, has been a major step forward in coastal ocean dynamics.

Impact and Outlook

During the Decade, physical oceanographers studied large-scale air-sea interaction in the North Pacific, mid-ocean mesoscale eddies in the western North Atlantic, initiated a systematic quantitative investigation of the Southern Ocean, and collaborated with biologists, and to a lesser extent, chemists and geologists. They mounted large coordinated research efforts directed toward selected phenomena in each of the major oceans bordering the United States. They undertook research on an ill-defined major ocean current system in a remote region of the world, which required a substantially organized, cooperative approach for definitive progress. They carried out a series of process-oriented joint physical/biological studies on coastal upwelling relevant to fisheries, which represented a pioneering effort because of its interdisciplinary nature and because of its applied intent.

IDOE physical oceanographers and their sponsors *did not* direct major efforts toward research in shallow estuaries, the Arctic, or the Indian Ocean, or on surface and internal gravity waves, or on fine structures of temperature and vertical mixing processes, or major mid-latitude current systems (such as the Gulf Stream and Kuroshio, or the rings that they spawn), nor did they commence global or long-term monitoring of physical variables. Important topics were omitted because they did not require large focused efforts, or because they would be studied under other auspices, or because of limited human and material resources. Some potentially significant studies were not pursued because of inadequate scientific background and the lack of technological capability. By and large, the projects carried out advanced our knowledge of the phenomena with which they were concerned at a more rapid pace than would have been possible if the IDOE had not existed. In addition, their successes and failures in philosophy, organization, and logistics left behind a legacy of know-how for big science in oceanography. The growing pains are partly over for this vital component of global marine science.

Although the major programs in the Atlantic and Pacific were designated investigations of phenomena and were in fact slanted toward general processes, they developed directly from pre-existing regional research interests. American oceanographers had a long-standing interest in turbulent eddies from study of the Gulf Stream and the Sargasso Sea, and in large surface pools of unusually hot or cold water off the west coast, which were thought to affect weather patterns sweeping in off the ocean. Mesoscale eddies exist throughout the world ocean, but are dominant in the western, rather than the eastern, North Pacific. Sea-surface temperature anomalies are known to exist in the North Atlantic, but they probably influence European weather and climate to a larger degree than American. The process orientation had important general and international consequences. In both MODE/POLYMODE and NORPAX, American oceanographers adopted the general process approach to the study of selected phenomena because some prior knowledge existed and logistics were relatively easy. This approach, coupled with multi-institutional and international participation, made these programs scientifically effective beyond the limits of their specific experimental domains. Mesoscale eddies have been discovered in all the major ocean basins and are being explored by regional scientists on a worldwide basis. NORPAX results are having an impact on various aspects of the developing World Climate Program. In MODE/POLYMODE, NORPAX, ISOS, and CUEA, multinational participation and the rapid communication of results in international forums are contributing to the dissemination throughout the international scientific community of important new ideas and methodology in physical oceanography.

Throughout the IDOE, project scientists were forced to make judgment decisions on the importance of phenomena and to design models and experiments without knowing in detail what they were pursuing. This is characteristic of the status of physical oceanography in general. Phenomena are first identified on the basis of a few suggestive observations, which serve as the basis for the explorations necessary to describe the scales and local characteristics (or kinematics) of phenomena themselves. The determination of the size and shape of eddies, the triple jet structure of the Antarctic Circumpolar Current, the depth and duration of surface temperature anomalies, and the basin-wide scale of the El Niño were all accomplished during the Decade. Only after the general numbers characteristic of phenomena of interest were available could scientists lay out research plans appropriate for the design of crucial dynamical experiments and the construction of pertinent models. The coming years must be devoted not only to attacks on new topics, but must also be vitally concerned with critical dynamical experiments and the acquisition of definitive data

sets based on a prior knowledge of sampling requirements. As the kinematics of phenomena become known, scientists can return to old data sets and find valuable information unextracted before because of insufficient knowledge. The analysis of historical data sets provided cost-effective scientific results to all the major IDOE projects. Kinematical knowledge, of course, is required for the design of smart, specialized, efficient instruments. It also is an essential preliminary to practical and interdisciplinary research efforts. Physical oceanography is entering a new quantitative era of dynamics, interdisciplinary research, and applications.

The new dimension in physical oceanography is an element of big science. It consists of purposeful, cooperative, large, sustained research programs. It is an unquestionably essential component of our science if the goal is to achieve efficiently and in the foreseeable future useful data sets and models truly representative of the ocean on the natural time and space scales of interest. The necessity for big science does not imply that smaller research projects, involving only one or a few investigators, are not important; many problems in physical oceanography today are more suited to such a strategy. Small independent projects often are, and need to be, part of big science programs. The opportunities for the individual scientist to function creatively in the field are enhanced, not diminished, by the new dimension because of the broadening of the class of accessible problems. Furthermore, although a big science approach may be needed when a phenomenon is first explored, smart, smaller projects may be preferable after enough is known about the phenomenon and the methodology of its investigation.

We know frustratingly little about the physics of the sea, although some inroads have been made and the overall nature of the scientific task required is becoming clearer. Modest as the successes may be, they have general interest beyond oceanography itself. In dealing with a large planetary-scale natural turbulent fluid system, the physical oceanographer draws from the experiences of the meteorologist, fluid dynamicist, and geophysicist, attempting to share common problems. The oceanographer can bring a fresh viewpoint, having neither the advantages nor the technical or intellectual inertia associated with an existing arsenal of instruments, an established observation network, or traditional models. Special circumstances and limited data encourage the oceanographer to explore new relationships between data sets and ideas. The multiscale world ocean model that is beginning to emerge is a rather sophisticated "hypermodel," composited from various existing models that were constructed for special purposes. Their interconnection presents technically and philosophically challenging problems. The optimal way to combine data sets, models, and isolated observations to provide the best description of how and why the water moves is an important contemporary research problem. The classical idea of using experimental data to test models and hypotheses is now only part of the story as the scientific system itself evolves. In beginning to cope with the vast, complex sea, the physical oceanographer has not only progressed from naturalist to quantitative scientist, but has moved to the frontier of modern scientific methodology itself.

Allan R. Robinson is Gordon McKay Professor of Geophysical Fluid Dynamics and Chairman of the Committee on Oceanography at Harvard University. He serves as Co-Chairman of the POLYMODE Organizing Committee and was Co-Chairman of the MODE Scientific Council. William Simmons was a physical oceanographer at the Woods Hole Oceanographic Institution until 1974, when he became Executive Scientist in the MODE/POLYMODE program. In 1977, he became Oceanographic Program Scientific Officer in the First GARP (Global Atmospheric Research Program) Global Experiment (FGGE).

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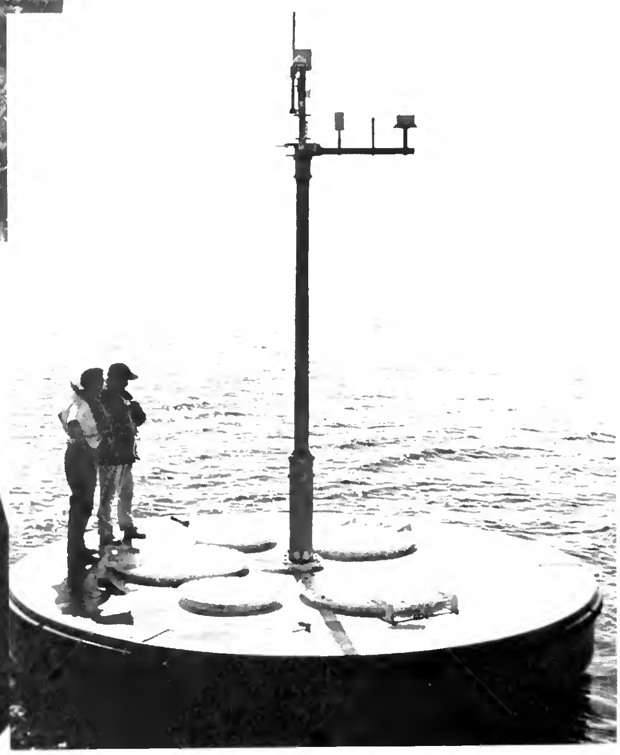
IDOE



Upper left, the long-spined sea urchin, Diadema antillarium, *feeding on Caribbean reef seagrass. Study of urchin's habits was part of Seagrass Ecosystem Study (SES). Above, a SODS buoy, which was used to measure thermocline oscillations and a bottom mixed layer during the CUE-1 experiment that was a prelude to the Coastal Upwelling Ecosystem Analysis (CUEA) program. At left, researcher in Canada collecting data in mobile laboratory for the Controlled Ecosystem Pollution Experiment (CEPEX).*

BIOLOGY PROGRAMS

by John D. Costlow and Richard Barber

The original plan of the International Decade of Ocean Exploration (IDOE) envisioned an international, interdisciplinary, and interinstitutional approach during the decade of the 1970s to a more comprehensive understanding of oceans and ocean processes directed toward more effective utilization of the sea and its resources. The six basic objectives identified by the National Council on Marine Resources and Engineering Development in 1969 included preservation of the ocean environment; environmental forecasting; an assessment of the seabed for improved utilization of mineral resources; the development of an ocean monitoring system to facilitate prediction of oceanic and atmospheric conditions; the improvement of worldwide data exchange programs; and a planning process to encourage opportunities for international sharing of responsibilities and cost of ocean exploration.

For reasons that are not, and were not, totally clear to the working scientist, there was no reference to biological or living resources in the original objectives. It should not be surprising, therefore, that the IDOE initially developed by the National Science Foundation (NSF) had no general program area devoted to biological research. This deficiency, the subject of much discussion in the two years that followed the announcement of the IDOE, was formally noted in 1971 in the first review of the IDOE. The review stated: "We believe that the present exclusion of living resources from the NSF-IDOE program of research programs should be rescinded" (NASOAB-NAEMB, 1971).

Subsequently, a fourth program was added to the already developed Environmental Quality, Environmental Forecasting, and Seabed Assessment programs. This fourth program area, Living Resources, was intended to provide a better understanding of the processes and relationships existing between the biological aspects of marine organisms and the chemical, physical, and geological environment in which they live. Living Resources was to be the new home of a program earlier developed under Environmental Forecasting — Coastal Upwelling Ecosystem Analysis (CUEA). As originally described, CUEA (or as initially named — CUE-I) was a field and modeling program largely in physical oceanography. Appropriate biological parameters were added through its transfer to the Living Resources program. It was not until 1974, however, that the Seagrass Ecosystems Study (SES), a biological program, was to emerge within the Living Resources program.

Two other projects — Controlled Ecosystem Pollution Experiment (CEPEX) and the Pollutant Response in Marine Animals program (PRIMA) — were developed within the Environmental Quality program in 1973 and 1978, respectively. Both of these programs had major biological components and are thus included among the four programs considered in this reflection on IDOE, 1970-1979.

Coastal Upwelling Ecosystems Analysis

The Coastal Upwelling Ecosystems Analysis (CUEA), is a multidisciplinary research program investigating coastal upwelling and its biological consequences. The CUEA grew out of a series of earlier studies in upwelling regions, but its direct antecedents were investigations done off the coast of Peru in 1966 and 1969 and studies of upwelling in Oregon begun by Oregon State University in the mid-1960s. The biologists and physical oceanographers who worked off the coast of Peru saw the need for collaboration. Thus by the time the IDOE was initiated, there already was a good working relationship between the scientists in the CUEA interdisciplinary group. In the IDOE mandate, they found an opportunity to form an integrated multidisciplinary research team that would concentrate resources and talents on a series of comparative experiments in several of the major upwelling regions of the world.

The original specific goal of the program was to predict phytoplankton distribution and growth in upwelling ecosystems on the basis of mesoscale observations of the critical forcing processes, mainly wind and circulation, but also including the biological processes of grazing, predation, and nutrient regeneration by zooplankton, fish, and benthos. Since phytoplankton are the base of the pelagic food web, culminating in commercially important fish, basic knowledge of phytoplankton dynamics seemed to be *sine qua non* for rational ecosystem management and conservation of the living resources in upwelling regions. Attainment of a basic understanding of the physical and biological processes of the lower food chain, with the assumption that others would put this knowledge to

work managing the living resources, was the overall goal of the CUEA scientists when the program was designed in the early 1970s.

The CUEA developed four main research objectives:

1. To describe the mesoscale distribution in space and time of the variables defining the ecosystem, including radiation, wind, currents, density, nutrients, phytoplankton, zooplankton, nekton, and benthos;
2. To identify and measure the processes that determine the properties of the system, including the wind-induced upper-ocean circulation, the mesoscale flow field, nutrient uptake and photosynthesis by phytoplankton, grazing and excretion by zooplankton, heterotrophic processes, and benthic regeneration;
3. To document the particular connections between physical and biological processes that combine in coastal upwelling ecosystems to increase production at least an order of magnitude greater than the biological production typical of other regions of the oceans;
4. To develop a series of simulation models of the upwelling ecosystems that provide the basis for predicting the response of upwelling ecosystems.

The CUEA field programs designed to implement these four objectives were unorthodox in that the scientific plan attempted to document synoptically an entire cyclic process (Figure 1), from the atmospheric forcing functions to the physical and biological responses of the ocean. This plan required that a complex of shore-based meteorological stations, moored current meter arrays, aircraft, and vessels operate simultaneously in a single, defined region. The IDOE directly supported 25 principal investigators from 13 American institutions and one Peruvian, and in the African and South American studies two West German institutions played a large role with ships and current meter arrays. A total of eight countries (United States, Peru, West Germany, France, Spain, East Germany, Mauritania, and Poland) had ships working at one time or another in the CUEA sites during the intensive periods; collaboration with these scientists has ranged from being very thorough (West Germany and Peru) to very slight (Poland).

Six field programs were carried out by the CUEA. JOINT-I and JOINT-II were the culmination of the CUEA program's previous experience in four smaller field operations: two primarily physical studies, CUE-I and CUE-II, working off Oregon in the summers of 1972 and 1973; and two primarily biological studies, MESCAL-I and MESCAL-II, working off the coast of Baja California in the spring of both 1972 and 1973. In the pilot MESCAL and CUE

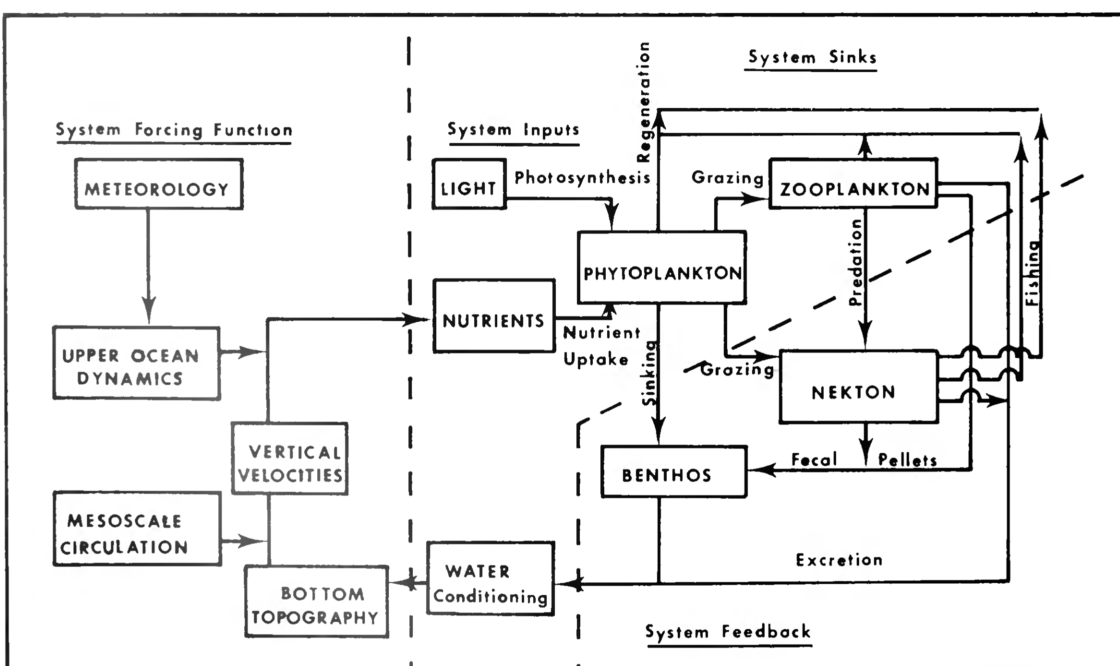


Figure 1. The initial concept for the coastal upwelling ecosystem. It was the basis of the CUEA program structure and investigator participation.

work, the multidisciplinary integration that would be necessary in JOINT-I and JOINT-II was developed.

JOINT-I was conducted off northwest Africa from February through May, 1974. Cooperation with scientists in CINECA (Cooperative Investigations of the Northern Part of the Eastern Central Atlantic) made possible a large experiment involving ships, aircraft, equipment, and personnel from eight countries. The United States provided three research vessels *(Atlantis-II, Gilliss,* and *Oceanographer),* an aircraft from the National Center for Atmospheric Research (NCAR), and 10 shore-based meteorological stations.

The second major expedition, JOINT-II, was a binational effort of the United States and Peru. Work was centered at 15 degrees South off the coast of Peru during three periods: March-May, 1976 (MAM 76); July-November, 1976 (JASON 76); and March-May, 1977 (MAM 77). Observations were made from seven American research vessels *(Alpha Helix, Thompson, Eastward, Melville, Cayuse, Wecoma,* and *Iselin),* NCAR aircraft, satellites, and eight shore-based meteorological stations. Peru provided two ships (*Snp-1* and *Unanue*), plus logistic support for the aircraft and meteorological stations; and the Instituto del Mar del Peru provided a coordination center in Lima.

The results of the field and laboratory work are recorded in 67 CUEA Data Reports and 61 CUEA Technical Reports that are available through the National Oceanographic Data Center (NODC) in Washington, D.C., or the CUEA office at Duke University Marine Laboratory, Beaufort, N.C.

It is difficult to quantify and evaluate the productivity of CUEA now because most of the synthesis is in press, in review, or in preparation. Since 1973 there have been slightly more than 150 papers published or accepted for publication in refereed journals. In addition, CUEA results have appeared in several symposium volumes (see Suggested Readings at end of article).

On the basis of the published work, it is possible to cite a series of advances resulting from this $16.1 million project. CUEA research tests the hypothesis that upwelling results from the tight coupling of a set of physical and biological processes, that this coupling is understandable, and, hence, that there is a basis for long-term management and use of the biological resources of upwelling ecosystems. CUEA's accomplishment has been to identify the coupling and to determine the quantitative nature of the physical/biological connection. CUEA work has established the relationship between local winds and productivity (*Deep-Sea Research,* 1977) and, less precisely, the relationships between very large-scale variations and the productivity and nature of the ecosystem. Given any coastal upwelling regime, with knowledge of its shelf width and latitude, we can now make a prediction of how variations in the local winds will affect the primary productivity. For example, in the northwest African region at the latitude of Cape Verde or Dakar, increased storm frequency will enhance primary productivity, since in those regions there are frequent periods of nutrient depletion in the surface coastal waters. Further north at the latitude of Cap Blanc, primary production is frequently limited because of deep mixing; thus, increased storm frequency there will decrease productivity. This general understanding provides a mechanism for predicting alterations in phytoplankton productivity and composition caused by changes in the local meteorology and climate.

As a result of the MESCAL-I and MESCAL-II expeditions to the Baja California coast, the role of weak, early upwelling in the initiation of dinoflagellate blooms and the role of strong winds and upwelling in the replacement of dinoflagellates by diatoms has been clarified to the point where preliminary predictions of these events are possible (Walsh, 1977). The importance of these predictions is underscored by recent work showing that certain first-feeding fish larvae must have dinoflagellates of a certain size and concentration to survive.

The importance of the event time scale in upwelling processes has been documented (*Deep-Sea Research,* 1977) and successfully modeled (O'Brien and others, 1977). Fluctuations in the local wind determine event time scale. Periods of strong winds favorable to upwelling are interrupted by a few days of slack winds on time scales that vary regionally; for example, off Oregon the event time scale is several days to a week, whereas off northwest Africa and Peru it is a week to several weeks. Phytoplankton growth rates are closely linked to these wind events, as are large fluctuations in the currents over the continental shelf and slope. Complexity of the abiotic-biotic interactions caused by local wind variations is evident in the phytoplankton population response. Changes in the zooplankton composition in the mid-shelf region off Peru were heavily influenced by event scale changes in the surface layer advection. The transport function of the upwelling circulation plays a key role in determining what species of phytoplankton and zooplankton can persist in the spatially restricted upwelling ecosystem (Barber and Smith, 1980).

Vertical transport in coastal upwelling is now known to occur within a narrow region, not broader than 50 kilometers offshore, and the effect of shelf and slope topography is evident in the location of intense upwelling. Off northwest Africa, where the shelf is narrow and wide, but the slope very steep, the coldest surface waters are observed just inshore of the shelf break. In contrast, off Oregon and Peru, where the shelf is relatively steeper and narrower, the most intense upwelling is next to the coast in a

narrow band. Observations confirm the theoretical modeling which indicates that patches of intensive upwelling should be located close to the heads of underwater canyons and on the equatorward sides of capes. There are distinctly different alongshore and onshore/offshore flow regimes among the upwelling regions investigated by the CUEA and these structural differences determine the nutrient, oxygen, and regeneration character of the various ecosystems.

Alongshore propagation of coherent current fluctuations in the upwelling region has been observed over alongshore scales of 700 kilometers (Smith, 1978), and there is some evidence that these fluctuations propagate as forced or free continental shelf waves and may propagate an upwelling event away from the local wind forcing. Despite the importance of the event time scale and local topography, the high alongshore coherence of the currents provides an overriding mechanism affecting the productivity of the entire coastal upwelling ecosystem. A poleward undercurrent flowing counter to the surface flow has generally been inferred for most coastal upwelling regions, but in the CUEA experiments it has been delineated and its variations have been measured for the first time. Variations in the depth and strength of the undercurrent determine the ability of vertically migrating organisms, such as dinoflagellates, anchovies, or photosynthetic ciliates to stay in the coastal system.

The mesoscale resolution achieved in the 1976 Peru field studies showed that large-scale, remotely-driven variations in the circulation pattern can override the local atmospheric driving and cause a complete change in the biological character of the system. The vulnerability of local forcing to overriding by remote forcing appears to be a function of distance from the equator. In this context, it is clear that the next step in understanding and predicting the natural variability in coastal upwelling requires work on equatorially propagated phenomena and the coupling of equatorial dynamics to coastal processes. It is also clear that the causal processes affecting phytoplankton involve phenomena operating on relatively small length scales of 5 to 10 kilometers. This domain, frequently called the frontal or plume structure scale, was not well resolved in the CUEA, which investigated mesoscale processes over length scales of 10 to 100 kilometers. The CUEA mesoscale understanding defines the large- and small-scale phenomena that are important to the upwelling ecosystem; this understanding may be the most valuable heuristic contribution of the CUEA.

Obviously, the CUEA has increased the store of basic knowledge about upwelling; but how well has it reached its four research objectives? The first two objectives — description of the variables that define the ecosystem and quantification of the critical processes — are largely completed. The third objective, elucidation of the physical/biological processes that make upwelling uniquely productive, is on the way to realization but not nearly finished. Work on it will continue for several more years, since each synthesis of the physical, chemical, and biological interrelationships suggests more interactions that need to be analyzed. Modeling accomplishments, especially in circulation (O'Brien, and others, 1977), have been substantial, but ecosystem modeling (Walsh, 1977) has yielded less insight than expected when the fourth objective was defined.

Like many other IDOE programs, the CUEA experienced its share of management problems. Probably the greatest was that the program grew too large for its resources, tending to add new components and investigators when no additional funding was available. Overall, however, the CUEA demonstrated that complex multidisciplinary and multinational expeditions could be carried out successfully anywhere in the world with the management skills of academic oceanographers (and their universities). During the CUEA, tight working bonds were formed between American oceanographers and those from the coastal nations of the upwelling regions; the contributions of developing countries (Mauritania and Peru) to the CUEA investigation, in relation to their gross national products, were large. In terms of developing lasting international relations, the upwelling work is an unqualified success; it remains to be seen if the new understanding can be put to work for society through the management of the living resources of upwelling.

Controlled Ecosystem Pollution Experiment

The Controlled Ecosystem Pollution Experiment (CEPEX), initiated in 1973, had three basic scientific objectives: 1) to determine the effects of various pollutants on the microbial, phytoplankton, and zooplankton components of a large, field-based experimental ecosystem; 2) to evaluate changes in nutrient uptake kinetics related to pollutant stress; and 3) to identify the chemical variations that may occur in experimental ecosystems subjected to pollutant stress over specific periods of time. The effort involved scientists from nine American institutions as well as Canadian and British scientists. At various times during the program, cooperative efforts also were under way with scientists from Japan and West Germany.

Initially, a great deal of effort and time was devoted to developing the experimental system for deployment in the field. Eventually different sizes of double-layered large plastic bags, or controlled experimental ecosystems (CEEs), were developed, field tested, and suspended in the Saanich Inlet, approximately 2.7 kilometers offshore from the

Institute of Ocean Sciences, Sydney, British Columbia, Canada, one of the participating institutions in this international effort. The capacity of the CEEs ranged from 68 to 1,700 cubic meters. In most experiments, three CEEs were involved simultaneously.

The basic experimental plan of the CEPEX was to trap large volumes of Saanich Inlet water with the associated organisms, and then to measure changes in temperature, salinity, nutrient concentration, zooplankton, and phytoplankton for periods of up to 60 days. Measured amounts of a variety of pollutants were introduced into the experimental bags, and daily or weekly changes compared to those observed in the control bag. The CEEs were open to the atmosphere. Organic debris was collected from the bottom.

Within the CEEs a variety of experiments were conducted — where possible, using two of the plastic bags as experimental replicates with the remaining one as the control. The results of these experiments, from 1974 to the present, have appeared in 82 scientific publications in a wide range of American and international journals. An additional 11 manuscripts have been accepted for publication and eight manuscripts are identified as submitted for review. Topics considered in these 101 articles include general descriptions of the experimental system, results from a number of ecological experiments, detailed accounts of the physiological, behavioral, or biochemical response of individual species to the CEEs or pollutants, and descriptions of various responses of one or more species of the major target organisms to specific stresses in the form of natural factors, heavy metals, and petrochemical compounds. (For detailed information on these experiments, see CEPEX — *Bulletin of Marine Science,* and CEPEX — *Marine Science Communications,* in Suggested Readings).

General results and conclusions have been attempted by several of the Principal Investigators. Originally, the planners of the CEPEX stressed that small-scale laboratory experiments to determine the effect of pollutants on a wide variety of marine species had provided unrealistic results, primarily because they were out of context in relation to the complex interrelationships known to exist in marine ecosystems, relationships that cannot be simulated in beakers or bottles. The large-scale CEEs were intended to at least reduce this disparity and provide more realistic results from systems that more closely approximated the natural marine environment.

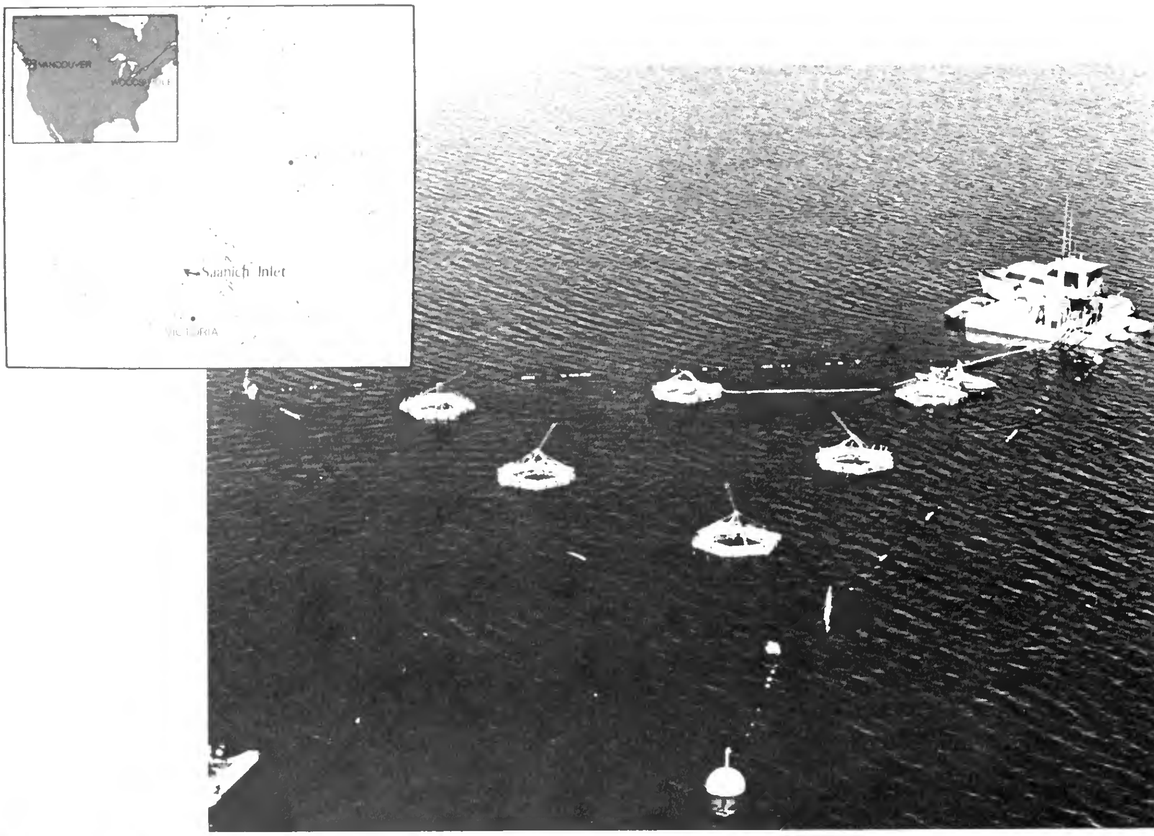
Although no definite assessment of the overall scientific results has yet been published, since data analysis is still in progress, CEPEX investigators point to several general conclusions that have emerged from their research. In a recent article, Gibson and Grice (1980) summarize some of these results: they feel CEPEX has shown that while bacteria and phytoplankton respond in large plastic bags much as they do in conventional laboratory glassware, zooplankton react to pollutants in lower concentrations in CEEs than in laboratory tests. According to Gibson and Grice, the results of CEPEX also indicate that susceptibility to toxic compounds is a function of size: for example, adults are less sensitive than juveniles, and large organisms are less sensitive than small organisms. At the level of the population, generation time is given as a prime factor in determining recovery. Thus, bacteria, with extremely short generation times and large numbers of species, demonstrate rapid recovery with resistant strains. Zooplankton recover more slowly and phytoplankton are considered to represent an intermediate area. They conclude that the observations of CEPEX further stress the inadequacy of the traditional, short-term, single-species toxicity tests as realistic assessments of effects of pollutants in the natural environment.

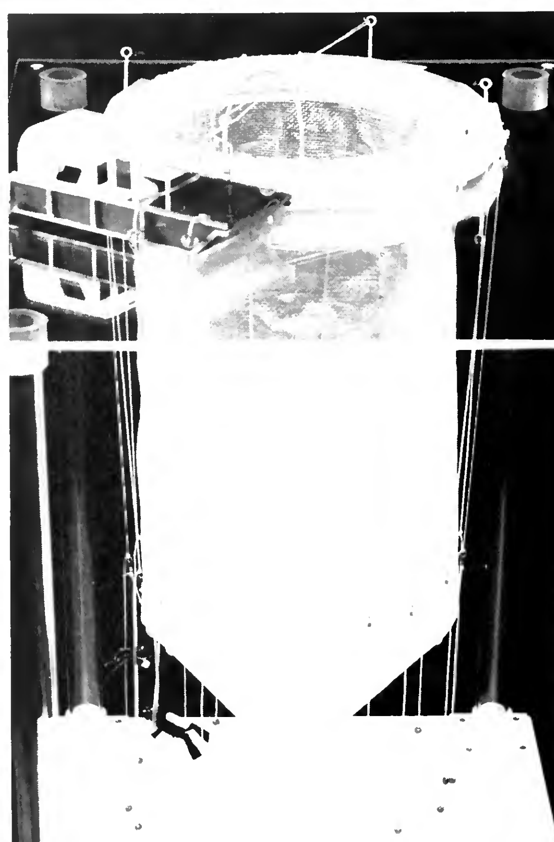
In a third general conclusion, Gibson and Grice hypothesize that the same sequence of events or responses is produced by exposure of the ecosystem to different pollutants: for example, the marine ecosystem responds in the same way to fluctuations of natural factors, such as nutrient turbulence or light, as it does when subjected to unnatural concentrations of most man-made pollutants. Menzel (1978) interprets the results of CEPEX to mean that despite the alarmist proclamations by several internationally known figures, the oceans are not dead and demonstrate a remarkable capacity to recover from localized perturbations.

In 1979, the National Science Board of the NSF terminated the CEPEX project. The Board gave no official reason for its action, although correspondence indicates the decision was made largely because of changes in the scientific purposes of the project, changes in investigators, and a change in institutions providing coordination and overall management. The estimated total cost of the project was $6.5 million.

As with many programs involving new technologies, CEPEX experienced a variety of administrative, scientific, and technical problems. For example, development and operation of new enclosures cost more than originally estimated. These same difficulties in design, construction, and deployment of the large CEEs resulted in delays in initiating the experiments. Because of the relatively long duration of each experiment, only two experiments with the largest CEEs were practicable in any one year, although with the smaller bags up to six were possible. Further problems were encountered because for each experiment accurate replication and adequate controls within the three large experimental bags proved difficult to attain.

The absence of vertical movement in the water column within the CEEs provided a still





Top, small-scale plastic enclosures afloat in Saanich Inlet, Vancouver, British Columbia, Canada. Right, model of large plastic enclosure or controlled experimental ecosystem (CEE). Above, diver attaching hose to sediment collector at bottom of CEE.

further complication during the early years of the program. Efforts to correct this, through pumping, led to "bubbling" compressed air within the CEEs, but the improvement was not applied uniformly to all systems and led to some confusion in the interpretation of results. Although CEEs may be a more realistic volume relative to field experiments than conventional laboratory glassware, they still do not truly simulate field conditions. Because of this, one can debate the extent to which the results of CEPEX may generally be applicable to the management of marine pollution problems.

Even without NSF support, some of the Principal Investigators associated with CEPEX expect to continue portions of the program, tentatively hoping for an extension of approximately five years. The reorganized research team includes some of the original group from Canada joined by others from Japan and West Germany. Plans are developing to complete the modification of the hardware in time for new field experiments on *in situ* benthic communities, plus the organisms within water columns with a depth of approximately 25 meters.

Only time will determine if American scientists will continue to participate, and still more time will be required to allow the oceanographic community to decide the value and usefulness of the results obtained from CEPEX.

Seagrass Ecosystem Studies

The Seagrass Ecosystem Study (SES) evolved from the International Seagrass Workshop held in Leiden, the Netherlands, in the fall of 1973, although earlier in that year general concepts of the proposed program had been developed by a smaller group meeting in Fairbanks, Alaska. The workshop, representing participation by 37 scientists from 11 countries, developed three basic objectives: 1) to contribute to the theory of ecosystems by examining the structure and function of seagrass ecosystems; 2) to develop the ability to assess and predict the response capabilities of seagrass ecosystems to environmental perturbations; and 3) to provide evidence of the role of seagrass ecosystems in the world ocean. Within this framework of objectives, five general working groups were identified. These included productivity/physiology, systematic ecology, composition, consumer ecology, and oceanography. Priorities were established on the basis of national needs of participating countries and an International Seagrass Committee was established to oversee the program and maintain coordination and communication among its representative groups. Funding for the U.S. portion of the program — the estimated total cost of the program to date is $7 million — followed in August 1974, establishing Seagrass Ecosystem Studies as the second program within Living Resources.

The overall SES program was divided into three basic phases. Seagrass I was largely a literature-oriented effort with relatively little field work, although laboratory culture and some transplanting efforts were included. Interests within Seagrass I, which involved scientists from five American institutions, included man's use of seagrass, distribution, production and decomposition, environmental tolerances, and phenology and transplantation.

Within Seagrass II the number of participating American institutions increased to seven and the individual projects expanded to studies of succession, food webs, particulate detritis, biogeochemical cycles, and systematic ecology, plus an expansion of the earlier efforts on phenology, transplantation, and environmental tolerances. This phase of SES was intended to be a site-oriented, problem-oriented research effort, leading to a further definition of problems and goals for the organization and integration of Seagrass III.

Seagrass III, currently under way, has been concerned with succession of seagrass ecosystems in a number of different geographical sites, chosen largely on the basis of observations and experience developed within Seagrass I and Seagrass II. The third and final phase is also concerned with forecasting the development of the seagrass ecosystem and refining hypotheses that account for seagrass ecosystem development, or lack thereof, in specific geographical areas of the world.

In contrast to several of the other IDOE Living Resource projects, SES was initially designed to evolve as the program progressed. Initial emphasis was to develop a basic understanding of critical processes in the biology of seagrass plants. This shifted to place more emphasis on the ecosystem and an understanding of seagrass plants in an ecosystem context. Final emphasis, at least within the present time frame of the IDOE, was to arrive at an understanding of how the system responds, both structurally and functionally, in the environment in which it exists and what implications these changes may have for other systems that coexist with the seagrass ecosystem.

The SES is expected to terminate in 1980, even though portions of the work remain uncompleted and much of the data from Seagrass III remains to be analyzed and synthesized. Through 1978, 17 manuscripts, in preparation or actually published, are identified. These include reports on decomposition, the applied aspects of seagrasses, rates of productivity, food webs in seagrass ecosystems, and other ecosystem studies.

The SES appears to have made good progress toward achieving its original objectives. It also conforms well to the general objectives of Living Resources: it is in every sense international; it is interinstitutional; and it is interdisciplinary. Two areas that would have made it more

interdisciplinary unfortunately were deleted from the original plan: shallow water oceanography and geological studies. One view indicated that this, as well as some initial delay in starting the program, was the result of funding difficulties encountered with the NSF. At almost mid-Decade, the SES was in full operation within Living Resources, as were most other IDOE programs, and the National Science Foundation is assumed by some to have been either unable, or unwilling, to provide the necessary additional funding.

It would appear that both the organization and levels of communication in the SES have been far above average, especially for a biological program. One problem identified by a researcher in the SES, and presumably inherent in this type of scientific organization, was the management. Most scientists are not efficient or experienced as managers. In coordinated efforts involving numbers of scientists and institutions from many countries, some mechanism needs to be developed to provide for corrective measures as they arise.

The SES will now terminate, although the early time-phasing charts showed a 1981 funding year for final synthesis and writing, a final year that apparently has been dropped. The published results, plus the highly cooperative efforts and relationships that obviously have developed in the SES, lead us to anticipate other similar efforts involving this group of scientists as we progress into the new decade.

Pollutant Response in Marine Animals

The Pollutant Response in Marine Animals (PRIMA) program was initiated in 1978 within the Environmental Quality section of the IDOE, as a follow-up to an earlier Biological Effects effort. Its basic objectives and general design were first considered in 1971 at a Durham, New Hampshire, workshop on Marine Environmental Quality (NASOAB). Its goal was to develop and evaluate biological indices of impending pollution-induced damage to selected marine animals.

An important function of PRIMA has been to plan for a coordinated and integrated approach for examining a variety of responses to toxicity within a few species of marine animals, combining the expertise of chemists, biochemists, biologists, physiologists, immunologists, histopathologists, and statisticians.

Although a few publications have resulted from this effort, it is too early to attempt an overall review of progress, speculate on the extent to which PRIMA may have fulfilled its original objectives, or attempt to address success or failures of efforts at management and communication.

PRIMA represents a U.S.-IDOE program with advisory input from and planned coordination with groups in Canada, Britain, Japan, and Europe. While there are individual aspects to research undertaken in PRIMA, achieving its stated objectives requires an integrated effort. It is presumed that no specialized or expensive facilities are required, as in CEPEX, and, since most of the experimental animals selected are in shallow water, large and expensive ship facilities are not required. The estimated total cost of the project to date is $2.4 million.

Conclusions

As the IDOE terminates and plans within the NSF evolve for a second decade program, named Coordinated Ocean Research and Exploration Section (CORES), what have been the contributions of the biological oceanographic programs within the IDOE? In our opinion, they are numerous and might be placed in three general categories: scientific achievements, lessons in organization, and progress in the realm of management, within both the bureaucracy of the National Science Foundation and the scientific community itself.

Scientific achievements within biological programs of the IDOE, as with most progress in science, are difficult, perhaps impossible, to evaluate, especially when one considers that the programs are all still going on and too little time has elapsed for a reasonable assessment of the contributions. The quantity of contributions can be determined by tabulating the number of scientific publications, the number of pages, or the number of citations, but these measures of quantity are not indicators of lasting scientific advances. Evaluation of the quality of the lasting advances requires time for the new ideas to be tested and used by members of the scientific community other than those who did the original work. There is no question in our minds that we now have a better understanding of the impact of ocean pollution on certain natural processes in the ocean, the major objective of the Environmental Quality program; we also have an impressive scientific basis for the intelligent use and management of the marine resources dependent on seagrass and upwelling ecosystems. Attainment of that scientific basis is the basic goal of the Living Resources program. The real measure of progress is the extent to which this base of information will contribute to resolving major local and global problems of ocean use through research yet to be done. The intelligent application of this new knowledge, however, is a social and political problem: it is not, and never will be, a scientific problem. Many of the objectives set forth in *The Continuing Quest* (see page 68) are built on progress and understanding achieved through the results of the IDOE. Thus, in part, the success of the scientific achievements of the CORES will depend on what has been accomplished by the IDOE.

In the realm of scientific organization, major achievements stand out sharply. For perhaps the first time in many years, a relatively large number of

accomplished young biological oceanographers approached problems in oceanography with physical, chemical, and geological oceanographers, not limited to studies of the literature but in truly cooperative efforts in the field and in the laboratory. For biologists, to a far greater extent than for scientists within the other major disciplines, this is extremely important. Physical, chemical, and geological oceanographers can make significant contributions without any real application of biological ideas in their work. Because of the matrix organisms live in, biological oceanographers must be aware of the varying degrees of basic physical, chemical, and geological processes.

In the international realm, even though this portion of the IDOE did not develop as originally planned, the scientists who worked in the IDOE programs have an ever-broadening network of international associations and personal relationships. This network of solid, rather than superficial, connections will prove to be essential to the future resolution of a host of major oceanographic problems.

Progress in the realm of scientific management is, perhaps, almost as difficult to identify as the scientific progress itself. Some scientists discovered that they are not administrators, whereas in other programs management talent of the scientific community emerged from surprising sources. Scientists within IDOE programs became much more familiar with federal administrators than before, and vice versa. On both sides, this familiarization led to the development of a level of rapport that contributed to the smooth operation of some of the projects.

Initially, there was much discussion within the scientific community about the workshop syndrome by which projects were developed and funded: that is, individuals participating in NSF-sponsored workshops appeared to have a major advantage in developing proposals that were subsequently funded. An early review of the IDOE criticized the National Science Foundation for not providing adequate mechanisms for either the transfer of projects to agencies where the studies might be more appropriate or for the termination of projects judged to be unsuccessful or unworthy of further support. Most of these administrative criticisms were resolved during the Decade, but only time will tell if the management of the CORES will benefit from these earlier experiences.

There will always be divided opinions within the biological scientific community concerning the outcome of the IDOE. There will always be those who are convinced that more could have been achieved by using the same funds for a large number of small, individual projects. For those who participated personally in the IDOE, however, regardless of age or scientific rank, a large number believe that this first major experiment in tackling complex oceanographic problems with the appropriate scientific team was successful and an experience that will determine their scientific efforts for years to come.

John D. Costlow is Director of the Duke University Marine Laboratory at Beaufort, North Carolina. Richard Barber, a Professor, is Director of the Cooperative Oceanographic Program at the Laboratory. He also is a Principal Investigator in the Coastal Upwelling Ecosystems Analysis (CUEA) program.

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Scientists' Attitudes Toward Big Ocean Science

by Peter Francis Hooper

From the moment that the International Decade of Ocean Exploration (IDOE) was conceived in 1966, the program has been a controversial one among marine scientists. Initially, many oceanographers believed that the concept was a political gimmick manufactured by the Johnson Administration to deal with foreign policy problems. The scientists, therefore, were reluctant to participate in the early planning phase of the Decade because they did not consider it a serious scientific initiative. However, they eventually did — on their own terms. Their report, *An Oceanic Quest,* conducted under the auspices of the National Academy of Sciences and the National Academy of Engineering (NAS/NAE), recommended a wide range of research on a national and international level in the broad areas of environmental quality, environmental forecasting, seabed assessment, and living resources. It recommended, as well, programs for marine technology development and an improved system of national and international data exchange.

Most of the scientific projects suggested for Decade consideration were studies of deep-ocean phenomena. There was little to pacify the interests of scientists concerned with nearshore, coastal, and estuarine processes. Further, most of the recommended initiatives required interdisciplinary teamwork on a scale unfamiliar to most oceanographers.

As eventually implemented, the program bore little resemblance to its initial plan. The end product was more consonant with the routine expectations of the marine science community than with the initial dream. In addition, the Decade office that was established adopted a narrowly focused

operating philosophy that conformed closely to the basic science bias of its organizational home, the National Science Foundation.

Given this brief background, we are seeking here to identify the types of scientists who have become involved in IDOE projects and other "big" marine science programs, and to explore their attitudes toward the Decade concept. To do this, we are drawing on a survey (by mail in 1977) of 800 marine scientists affiliated with academic and research-oriented institutions throughout the United States. A team of researchers at the University of Connecticut, under the auspices of the Social Science Data Center located at that institution,* conducted the survey. In addition, this author obtained comments in interviews with approximately 40 administrators, scientists, and interested observers of the Decade.

Who Does IDOE Research?

Since IDOE began sponsoring research projects in 1971, oceanographers from all the major fields have succeeded in gaining research support, although biological oceanographers have always been underrepresented among the program's funding recipients. According to the University of Connecticut survey, only 15 percent of the IDOE funding recipients identified themselves as biological oceanographers, yet, nearly half of the oceanographic community has a biological orientation.** Chemical oceanographers are represented in roughly the same proportion in IDOE as they are in the general community (15 percent to 13 percent, respectively). Marine geologists and geophysicists (measured as one group) and physical oceanographers are both highly overrepresented in the IDOE program (40 percent to 21 percent and 30 percent to 19 percent, respectively).

Three characteristics, however, that best distinguish IDOE funding recipients from other oceanographers include a surrogate measure of one's institutional prestige (whether it is a major research vessel-supporting institution), one's connection to the federal funding network, and one's research orientation (basic or applied).

First, the program primarily has attracted scientists affiliated with the major research vessel-supporting institutions. According to the results of the survey, almost 30 percent (29.2 percent) of the scientists from the major ship-operating institutions have received IDOE funding compared to 17.7 percent from the medium-sized ship-operating institutions, and 10 percent of the scientists from the institutions with only coastal vessels or none at all.

Second, IDOE science tends to attract scientists who are more closely tied into the federal funding network (Figure 1). Considerably more than half (62.5 percent) of the IDOE-supported scientists have received grants or contracts from at least four federal agencies, whereas only 29.2 percent of the others have done so.

Third, although IDOE scientists are likely to receive research support from a greater number of federal funding sources than their counterparts, they also are more discriminating. That is, IDOE fundees prefer funding from agencies that are supportive of basic science investigations, such as the National Science Foundation or the Office of Naval Research (ONR), than those which support applied or directed studies, such as the Energy Research and Development Administration (ERDA), now the Department of Energy (DOE), the Environmental Protection Agency (EPA), or the Bureau of Land Management (BLM). As indicated in Figure 2, nearly half of the IDOE fundees describe their research as basic compared to roughly 30 percent of the others. Only 8.7 percent of the IDOE fundees characterize their scholarship as applied,

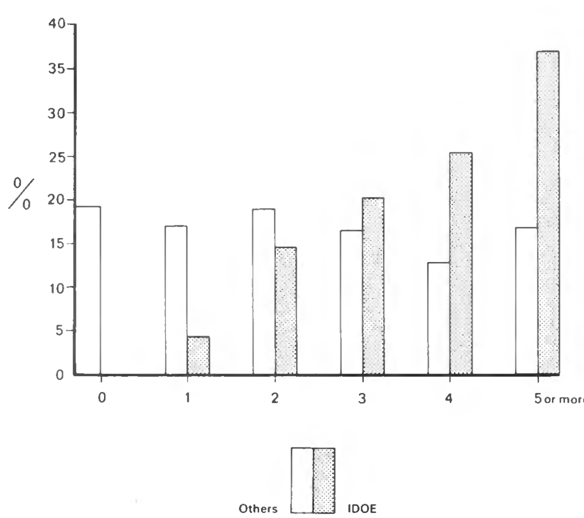

Figure 1. Number of federal funding sources by IDOE fundees and all others.

*The principal investigators in the study were Professors W. Wayne Shannon, David P. Palmer, and Everett C. Ladd, Jr. A random sample of approximately 1,500 individuals from the faculties and/or research staffs at 52 institutions offering at least 24 credit hours of oceanography or marine science were mailed questionnaires. The 800 responses represented a more than 53 percent return rate.

**No distinction was made on the part of the survey between biological oceanographers and marine biologists.

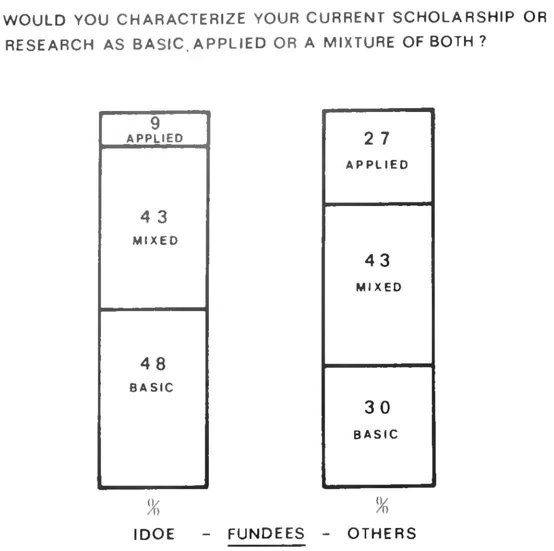

Figure 2. Type of research by IDOE fundees and all others.

compared to 27.2 percent of the other marine scientists surveyed.

These three characteristics — institutional affiliation, relation to the federal funding network, and research orientation — distinguish IDOE fundees from all other marine scientists. But, while IDOE funding recipients tend to be heavily weighted toward one end of the professional spectrum — one might characterize it as the elite or most prestigious segment of the community — not all the oceanographers with these characteristics are disposed to participate in large-scale, IDOE-type research. In fact, only 22.7 percent of the variation in the two groups (IDOE fundees and all others) is explained by the three principal distinguishing variables or characteristics.

What Are the Attitudes toward IDOE?

Even among IDOE fundees, the attitudes toward large-scale science are mixed. When asked if they prefer to engage in highly coordinated, large-scale projects, IDOE funding recipients did not differ significantly from other oceanographers. Only 5.2 percent of the IDOE fundees compared to 4.1 percent of the others indicated they always prefer the large-scale mode; 77.3 percent of the IDOE fundees and 62.5 percent of the others indicated sometimes; and 17.5 percent of the IDOE fundees and 33.5 percent of the others claimed never.

Majorities of both groups would prefer to see support for large-scale and small-scale research increased, but support for the latter is much higher even among IDOE fundees. Nobody would approve of cuts in small-scale research grants, but 6.4 percent of the IDOE fundees and 13.9 percent of the others indicate support for a reduction in expenditures in large-scale research even if the federal marine science budget were to be increased by 50 percent in real purchasing power over the next five years (Table 1).

Oceanographers remain divided over whether large-scale science is truly an effective use of limited financial resources. A typical argument is that "a lot of good science could be done with the money that is wasted in big projects with meetings, meetings, and more meetings." In addition, scientists generally believe that small-scale endeavors produce superior-quality results and that many wide-ranging interdisciplinary marine-related questions are simply not theoretically mature for adequate investigation. However, when asked to assess the quality of academic marine science work funded specifically by IDOE, they are more sanguine. Marine scientists rank IDOE sixth among a list of 15 federal funding agencies. Roughly 80 percent of the survey respondents consider IDOE science excellent or of generally high quality. Only

Table 1. Application of increased federal funding to oceanographic needs by IDOE fundees and all others* (percent by column).

Funding Level	*IDOE Fundees* Large-Scale Grants	*IDOE Fundees* Small-Scale Grants	*Others* Large-Scale Grants	*Others* Small-Scale Grants
Increase	61.8	91.7	55.2	95.7
Maintain current level	31.9	8.3	30.9	4.3
Reduce	6.3	0.0	13.9	0.0
Total	100.0	100.0	100.0	100.0
Number of respondents	(157)	(156)	(567)	(568)

***"If federal support for academic marine science were to be increased by 50 percent in dollars of constant purchasing power over the next five years, where would you like to see the new money applied?" (Small grants for basic research; large-scale grants for basic research.)**

the science funded by other sections within the National Science Foundation, and that supported by the National Institutes of Health (NIH) and the Office of Naval Research fare better (Figure 3).

But an assessment of the overall success of many of the individual IDOE projects demonstrates a wide variability about which it is difficult to make many generalizations. Perhaps the most important one is that the projects that have percolated up from the scientific community are more highly rated than those which are initially recommended or pushed by the IDOE program office. The Geochemical Ocean Sections Study (GEOSECS) and Climate: Long-Range Investigation, Mapping, and Prediction (CLIMAP) projects, for example, have a lengthy scientific prehistory and they receive nearly unanimous acclaim, while the pollution-based studies and the original manganese nodules project, which were pushed by the IDOE office, get the harshest criticism (Figure 4). Overall, some projects in each of the four program offices — environmental forecasting, environmental quality, seabed assessment, and living resources — are given high ratings and others low, although the projects supported by the environmental forecasting office appear to have a slight edge.

The academic marine science community is also generally pleased with the quality of its working relationship with the IDOE office. More than 80 percent of the respondents rate IDOE's administrative policies or style highly or generally satisfactory. Only the Foundation's Deep Sea Drilling Project (DSDP), Oceanography Section, and Environmental Biology program, and the Department of Health, Education, and Welfare's National Institutes of Health and the Defense Department's Office of Naval Research receive higher ratings. Despite its increased responsibility for overseeing the conduct of large-scale projects, the IDOE office has adapted as much as possible to the typical NSF administrative style by steering clear of interference with the scientific management of projects, and reducing administrative oversight by requesting only semi-annual progress reports. The IDOE office also has moved to eliminate administrative hassles during field work and other hectic stages of the projects by timing its paperwork requests during the slow periods or natural lulls in the projects.

When asked to focus on more specific positive and negative interactions with the federal funding agencies, clearly, as in the previous examples, scientists chose the agencies that reflect the dominant academic marine science biases — small-scale, basic science orientation, investigator autonomy — most frequently. Those at the other extreme fare worst.

Tables 2 and 3 compare only five programs from a longer original list of more than 20 federal funding sources, and since the Sea Grant program and the Bureau of Land Management have

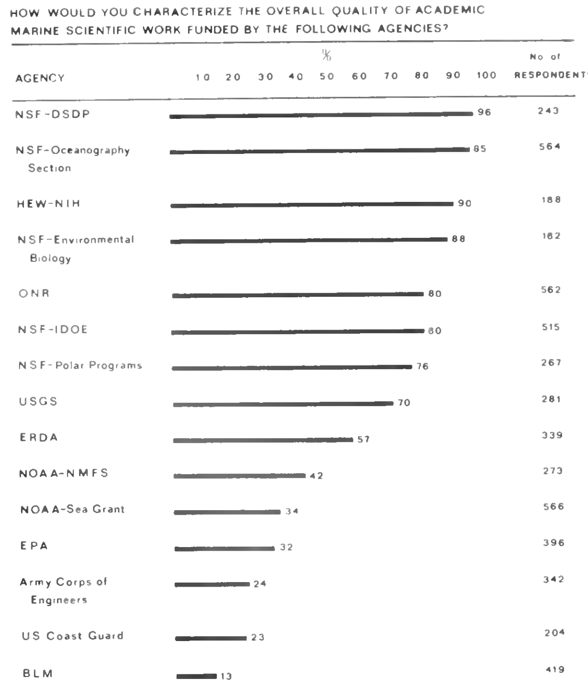

Figure 3. Assessment of the quality of academic marine scientific work funded by federal funding agencies. Percent bar represents excellent or generally high quality.

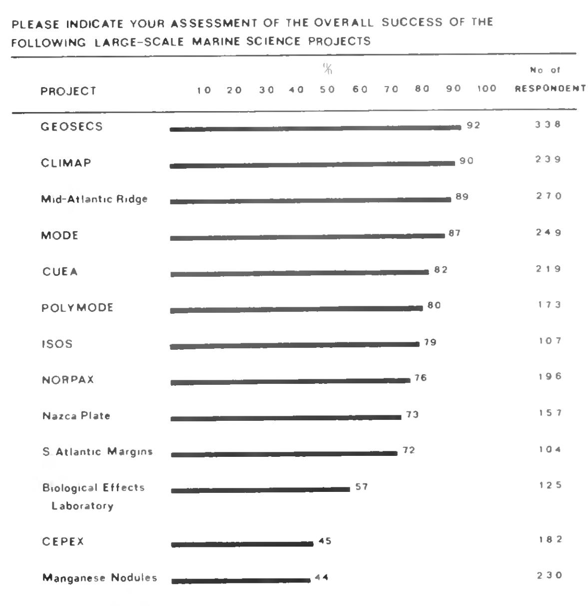

Figure 4. Assessment of the overall success of select IDOE projects. Percent bar indicates highly or generally successful.

Table 2. Assessment of positive experiences with the administration of selected federal agencies (data in percent).

Favorable Comments	Oceanography Section, NSF	ONR	IDOE	Sea Grant	BLM
Promptness in funding decisions	45.4	37.8	27.2	19.5	3.4
Competent program officers	44.6	34.4	26.3	14.1	4.0
Interest in my research	44.6	39.7	31.2	20.9	9.0
Creative and farsighted	20.4	16.9	17.2	8.9	3.4
Flexible in altering research directions	40.4	31.2	26.4	14.4	2.3
Number of respondents	(369)	(360)	(251)	(369)	(177)

responsibilities that go beyond the interests of academic research-oriented scientists, the more focused comparison presented here may not be an entirely fair one. Nevertheless, the five programs illustrate the range of responses to various positive and negative stimuli. Overall, the IDOE ranks highly on the number of stated positive experiences, although the Oceanography Section and the Office of Naval Research outdistance it considerably on most measures.

The IDOE ranks only in the middle of the list of agencies supporting marine science on the questions that prompt the respondents to identify negative experiences. The IDOE is singled out in particular for the quality of its program officers, which is apparently rather uneven and the cause of some concern within the Foundation. In addition, the IDOE is criticized for excessive delays that are sometimes encountered in the proposal review process.

One other criticism of large-scale programs that showed up elsewhere in the questionnaire indicated considerable dissatisfaction in the initial planning stages of the projects. An overwhelming majority of IDOE fundees and all other oceanographers disagreed with the proposition: "The process of initiating and planning new large-scale projects is sufficiently open to input from all parts of the scientific community." This finding most likely reflects the fact that in a small field, such as oceanography, the scientists who generate the project ideas know with whom they prefer to work. But, to those scientists who are not part of the communications network, and to the larger public, it may appear that there exists a rather tightly knit, closed elite that controls the selection process. In a personal interview with the author, one well-known oceanographer acknowledged that "we hand-picked the members of the research team." He went on to add that "it (IDOE) is by necessity a game for the big players, but it has to be that way because these people have proven their capability to work hard, to manage, to follow through." Another scientist proclaimed: "good science cannot be arrived at democratically."

In summary, IDOE-sponsored science is considered large-scale by marine science standards, attracting primarily oceanographers from the prestigious institutions that maintain the most sophisticated facilities and operate major

Table 3. Assessment of negative experiences with the administration of selected federal agencies (data in percent).

Unfavorable Comments	Oceanography Section, NSF	ONR	IDOE	Sea Grant	BLM
Delays in funding decisions	8.1	6.9	13.5	11.1	37.3
Obtrusive regulations	1.6	4.7	6.4	10.3	26.6
Discriminatory treatment	2.7	5.0	6.4	10.3	7.3
Inadequate funding	10.0	6.4	5.2	16.8	6.8
Incompetent program officers	8.1	18.3	16.7	27.1	38.4
No interest in my research	10.0	19.4	10.0	27.4	13.0
Number of respondents	(369)	(360)	(251)	(369)	(177)

oceanographic vessels. Yet, many oceanographers do not want to engage in IDOE science because they believe that the large-scale mode of operation is not the most effective approach to science, nor does it produce the highest-quality results. Despite the fact that the IDOE has adapted as much as possible to the National Science Founation mode of operation and organizational culture, it still is not considered as highly as other basic science-oriented, federally sponsored programs, which, perhaps, results from confusion about its political origins, and its early emphasis on a wider range of basic and applied goals.

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INDEX

VOLUME 22 (1979)

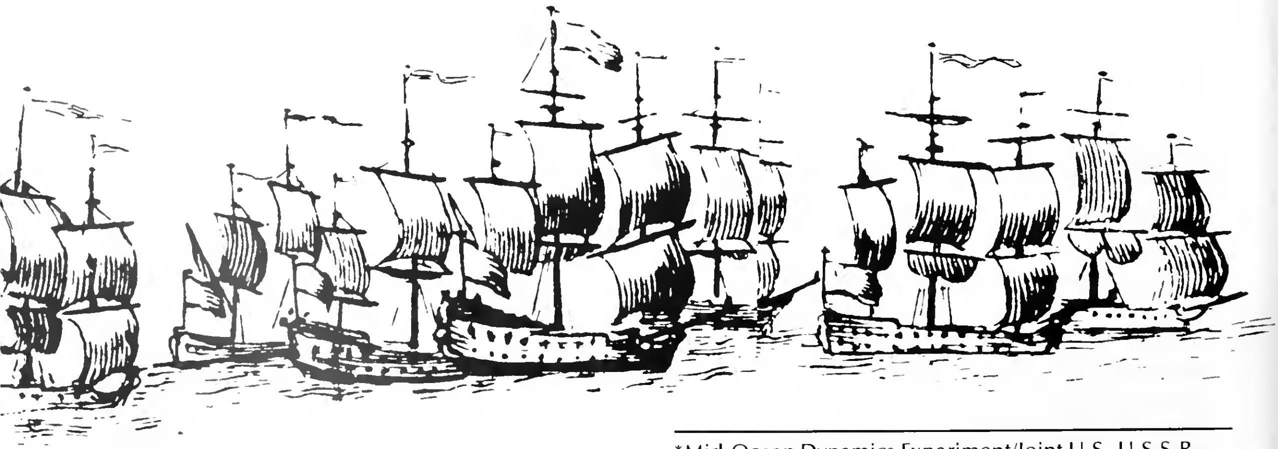
The Endless Quest

by Warren S. Wooster

The International Decade of Ocean Exploration (IDOE) was announced by President Johnson in March, 1968. Two months later, some features of the program were described in a White Paper released by the National Council on Marine Resources and Engineering Development (see page 2). But up to this point, the interest of oceanographers had not been mobilized, and only later was assistance sought from the National Academy of Sciences (NAS) and the National Academy of Engineering (NAE) to determine the substance of the program. I was asked by the NAS Committee on Oceanography to chair this study; William E. Shoupp of the NAE Committee on Oceanography was vice chairman. The steering committee first met in August, 1968, and a large workshop was held at Woods Hole, Massachusetts, in September. The report, entitled *An Oceanic Quest,* was issued in early 1969. Life was simpler then.

As it developed, the Decade bore considerable resemblance to the program described in the NAS/NAE report, not in the details of scientific projects eventually implemented, but in concept and style. The biggest discrepancy was in the level of funding. Oceanographers had proposed a much grander program than actually was created. But even with the limited resources made available, important joint projects arose that involved scientists from different institutions, disciplines, and countries. They tackled problems of larger scope and complexity than previously had been possible. Both the vocabulary and the substance of oceanography were enriched by studies such as MODE/POLYMODE, GEOSECS, CUEA, CEPEX, and CLIMAP*; some of the results of these and other IDOE projects are described elsewhere in this issue.

Unfortunately, like all good things, decades must come to an end. As early as 1975, the National Science Foundation asked the National Advisory Committee on Oceans and Atmosphere (NACOA) to review the IDOE and to make recommendations regarding its future. Not surprisingly, NACOA liked the program, endorsed continued NSF support for long-term, multidisciplinary, and multi-institutional studies, and proposed early consideration of a follow-on program. As it turned out, the National Academy of Sciences was again to be involved, but the planning process differed in several ways from the earlier exercise, particularly in the role played by the National Science Foundation.



*Mid-Ocean Dynamics Experiment/Joint U.S.-U.S.S.R. Mid-Ocean Dynamics Experiment (MODE/POLYMODE); Geochemical Ocean Sections Study (GEOSECS); Coastal Upwelling Ecosystem Analysis (CUEA); Controlled Ecosystem Pollution Experiment (CEPEX); and Climate: Long-Range Investigation, Mapping, and Prediction (CLIMAP).

In early 1977, the Foundation organized four disciplinary workshops to consider large-scale scientific opportunities in physical, chemical, and biological oceanography, and in geology-geophysics. Although participation in these workshops was limited (to about 30), a much larger group of scientists (some 400) contributed their ideas through correspondence.

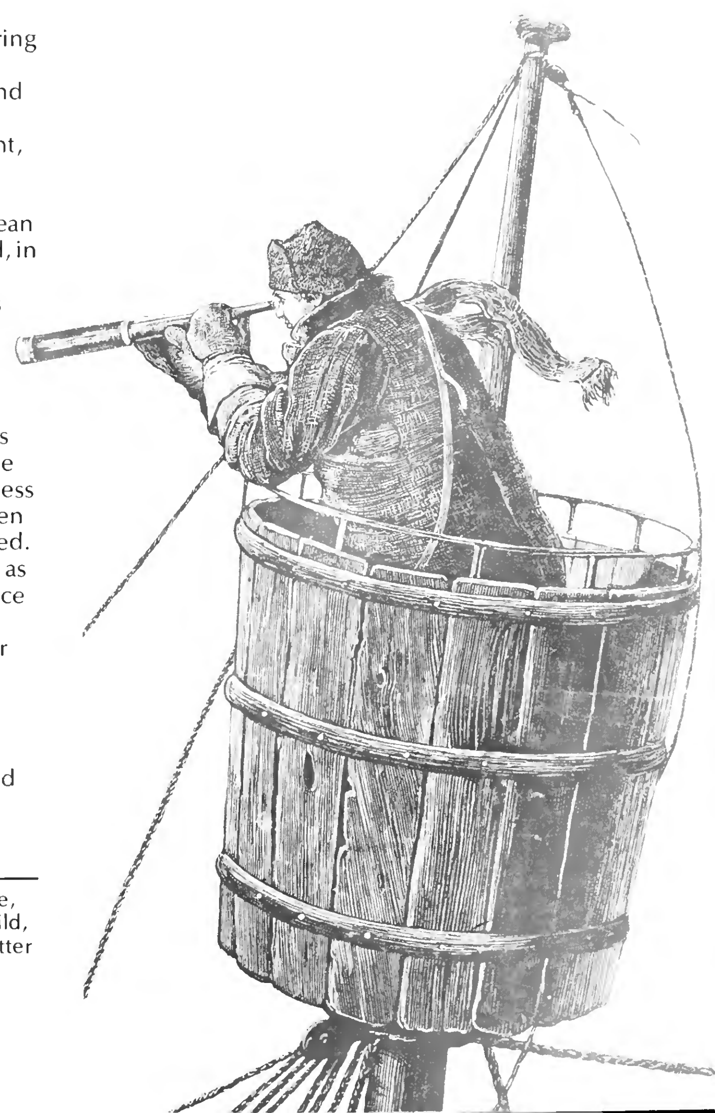
At about this time, the Foundation requested assistance from the NAS Ocean Sciences Board (OSB). I was asked to chair the steering committee, consisting of representatives from the OSB, the Ocean Policy Committee of the NAS, and the Marine Board of the NAE.* Our advice and participation was invited regarding the workshops, and we were asked to prepare specific recommendations for a successor to IDOE.

There was some question as to whether disciplinary workshops were the best way to identify promising scientific approaches to oceanic problems that were often inherently interdisciplinary. We were conscious of the need to look for connections among the proposals of the various workshops and to review critically the mechanisms and procedures that had arisen during the IDOE years. We also had to reconsider the relation between proposed research activities and the eventual application of their findings to problems concerning food, energy, environment, and climate. To consider such questions, a fifth workshop was convened; reports of all the workshops were published by the Center for Ocean Management Studies, University of Rhode Island, in August, 1977. Such general questions also were considered by a larger and more heterogeneous gathering in September, 1977.

After that event, I spent several months organizing and writing drafts of sections of the report, assisted by members of the steering committee who contributed most of the sections describing the scientific findings of IDOE and the oceanographic opportunities for the 1980s. Endless months of editing and revising followed, and then the lengthy review process of the Academy ensued. Finally, in early 1979, the product was published as *The Continuing Quest: Large-scale Ocean Science for the Future.* Most of what follows has been summarized in that publication; I shall endeavor here to identify some of the more controversial topics and discussions.

Although various phrases were used to describe IDOE projects — international, interdisciplinary, multi-institutional, applied, and "big science," few applied to all successful projects, or provided a reliable way to distinguish them from those funded elsewhere by the National Science Foundation or other agencies. Although many projects involved scientists from other countries, none was truly international in the sense of having comparable foreign participation and funding. Nor was any project truly interdisciplinary, although several were at least multidisciplinary and reflected a good deal of interdisciplinary thinking. Projects were "applied" only in the sense that social problems were identified early in their development. The IDOE promoted "bigger" science, but even the more expensive projects were small compared with major efforts in high-energy physics or outer space.

Perhaps "cooperative" is the best term to describe the IDOE, with the cooperation extending beyond single institutions, disciplines, and countries. Furthermore, this cooperation was developed on a large scale, with 10 or more



*Other members of the committee were John V. Byrne, Reuben Lasker, Foster H. Middleton, Brian J. Rothschild, Derek W. Spencer, and Ferris Webster. Richard C. Vetter served as Executive Secretary.

institutions involved in all of the major projects. Most projects lasted five or more years (some more than 10); and total project costs ranged from a few million dollars to more than $20 million. This sort of cooperation clearly paid off scientifically, and we felt it should be continued in a successor program.

It was important that there be cooperation not only among scientists, but also among agencies of the federal government. For example, we urged that mission-oriented agencies join in planning and funding projects that contributed to their objectives. This was seldom achieved during the IDOE — notable exceptions were NORPAX* and MODE/POLYMODE jointly sponsored by the National Science Foundation and the Office of Naval Research (ONR) — and there are no signs that it will be easier to achieve in the 1980s.

A problem that was both intriguing and controversial was the relation between the proposed program and applications of its findings. We agreed early that the objective should be broadened beyond that of IDOE and should be "to seek the comprehensive knowledge of ocean characteristics and their changes and the profound understanding of oceanic processes required for more effective utilization of the ocean and its resources, for protection of the marine environment, and for the prediction of natural events, such as weather and climate."

It was clear that the principal concern of the National Science Foundation was to fund high-quality fundamental research, and the main concern of the academic scientists was to carry out such research. Yet there are important societal problems, such as those mentioned in the statement of objective, whose solution depends on greater understanding of the natural systems involved. The reasons we thought a program of fundamental research was required were summarized in the report as follows:

1. *The context and significance of applied problems continue to change with the increase in the variety and intensity of ocean use. Whatever the problems of the moment may be, their solution eventually will be based on fundamental knowledge.*
2. *Oceanic phenomena and processes are complex and interactive. Interpretation of the results of application-oriented research usually requires an understanding of the underlying processes that can only be obtained by fundamental research.*
3. *Fundamental scientific knowledge is essential for predicting the consequences of alternative decisions on ocean use.*
4. *Fundamental research supports that which is application-oriented by generating new ideas and methods that can be applied to more immediate problems.*

*North Pacific Experiment.

For many scientists, the utility of fundamental research is to some extent an article of faith rather than a demonstrated fact. It is difficult at this time to identify many of the practical consequences of research done in the IDOE, although it is clearly too soon to expect returns on such a long-term investment. Since one might expect more practical minds to prefer funding of short-term, applied projects, it was particularly pleasing to note the strong support for fundamental research in successor IDOE programs given by the Marine Board of the National Academy of Engineering.

Another set of questions concerned the practices of review and management that developed during the IDOE. Projects that arose from workshops of invited scientists were reviewed by special panels and managed by committees of participants. Some scientists felt excluded from the process, whereas others complained that they were spending too much of their time proposing, reviewing, reporting, and managing, with no time left for research. But after considering the alternatives — for example, the unpalatable proposal that professional project managers be employed — the steering committee concluded that many IDOE procedures were still basically appropriate, the only changes proposed being those that might further ensure diverse approaches, open access, and equitable treatment of all potential participants. No one questioned that the ultimate criterion in selecting projects should be "a high probability of producing a significant increase in fundamental knowledge and understanding."

Much of our discussion was devoted to deciding on the kinds of projects that might be carried out in the 1980s. Our report listed some of the intriguing unanswered questions in each of the several pertinent disciplines and then went on to discuss how these questions fit into some larger interdisciplinary projects; for example, in estuarine and coastal studies, in equatorial dynamics, in the Southern Ocean, and in boundary layer processes. These ideas were not developed into the details of a project, because this might have appeared to give an advantage to scientists interested in that project, and also because by the time an IDOE successor program would be activated, new problems and ideas would be identified. Our examples were intended to give the flavor of the program, not to be a guide to successful proposal writing.

I shall leave discussion of the scientific problems of the 1980s to those who are more likely to solve them. Our examination of the scientific opportunities reassured us that the well was not running dry, that the growing community of oceanographers had far more promising scientific projects in mind than were likely to be funded in the foreseeable future.

This brings me to the question of a proper funding level for the program of large-scale cooperative ocean research in the 1980s. Although IDOE was a much smaller program than originally conceived, it brought $14 to $20 million of new money each year to the field, sums that constituted 11 to 16 percent of the total federal oceanographic research support during the 1971-1979 period. At the very least, we hoped to justify continuation of the program at a comparable level.

No one suggested that the post-IDOE program should grow at the expense of support for the projects of individual investigators. But some of us felt that the field as a whole was underfunded. Although we were not rash enough to propose the priority that should be assigned nationally to the support of oceanographic research, we did see reasons why it should be increased. These included the increasing use of the ocean and its resources, the growing potential for conflict among uses and users of the ocean, and the urgency for a stronger scientific basis for ocean policy decisions.

In addition to including a growth rate (a modest 3 percent), we estimated some other costs beyond those that had been normally associated with the IDOE. There seemed to be a gap between the relatively small grants to individual investigators and the million-dollar-a-year large projects, a gap where intermediate scale and pilot projects could give greater flexibility in trying out new ideas; we proposed investment at an initial level of $2.5 million per year for such projects.

The IDOE was a significant user of ships, and there is no reason to believe its successor will be different. In addition to operating costs (estimated at $11 million per year for the first year of the new program), an annual investment in ship refit and replacement is required, with the share of this program amounting to $2.9 million per year. Another significant incremental cost is that for replacement of major items of obsolete equipment and for the development, testing, and construction of new devices. Such support had been proposed (but never supported) as a separate item for the first Decade. Our estimates call for an initial annual investment of $2.5 million.

Finally, there are additional costs that arise from the newly developing legal regime for the conduct of oceanic research. Work in locations under the jurisdiction of another country, to the extent that it is permitted, is likely to entail costs ranging from rerouting of the ship to pick up coastal-state participants, through foreign travel in connection with pre- and post-cruise negotiations and conferences, to more extended activities in assisting coastal-state scientists to utilize information obtained in the research. We considered that these costs would amount to $1 million per year.

To summarize these estimates, starting from an initial basic program (extension of IDOE) of $25 million in 1981, the additional costs would bring the total to about $45 million. In 10 years, the program would grow to about $58 million annually in constant (1981) dollars, or to nearly $104 million with a 7 percent annual inflation rate.

Our discussion of funding, after presenting these figures, concluded: "The estimates do not provide for significant new scientific developments and opportunities, nor for accelerated growth due to unanticipated social demands. Nonetheless, we consider them a reasonable basis for planning within the constraints of present knowledge."

It is too soon to know how fully these recommendations will be accepted. Continuation of the IDOE has been approved, and a new National Science Foundation program — the Coordinated Ocean Research and Exploration Section (CORES) — has been established. There are no indications as yet that the funding level of CORES will be significantly higher than that of the final years of IDOE. Perhaps increases will come as the usefulness of this approach in ocean research is better appreciated and as the problems to which its results apply become more pressing.

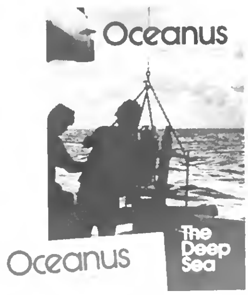
Our report stated: "We are convinced that a post-IDOE program of large-scale cooperative research is essential to the continuing quest for oceanic knowledge and understanding." That quest did not begin with IDOE, nor will it end with CORES. It is truly endless.

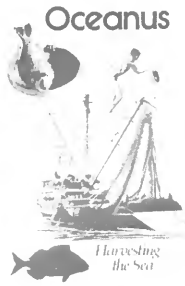
Warren S. Wooster is Professor of Marine Studies and Fisheries at the University of Washington in Seattle. He is also Chairman of the National Research Council's Ocean Sciences Board and is a United States delegate to the International Council for the Exploration of the Sea.

Additional Readings

National Academy of Sciences. 1969. *An oceanic quest.* Washington, D.C.

National Academy of Sciences. 1979. *The continuing quest.* Washington, D.C.





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ENERGY AND THE SEA, Vol. 17:5, Summer 1974 — *Very limited supply.*

FOOD FROM THE SEA, Vol. 18:2, Winter 1975* — Fisheries biologists and managers are dealing with the hard realities of dwindling stocks and increasing international competition for what is left. Seven articles deal with these problems and point to ways in which harvests can be increased through mariculture, utilization of unconventional species, and other approaches.

DEEP-SEA PHOTOGRAPHY, Vol. 18:3, Spring 1975 — A good deal has been written about the use of hand-held cameras along reefs and in shallow seas. Here eight professionals look at what the camera has done and can do in the abyssal depths. Topics include the early history of underwater photography, present equipment and techniques, biological applications, TV in deep-ocean surveys, the role of photography aboard the submersible *Alvin* along the Mid-Atlantic Ridge, and future developments in deep-sea imaging.

MARINE BIOMEDICINE, Vol. 19:2, Winter 1976* — *Very limited supply.*

ESTUARIES, Vol. 19:5, Fall 1976 — Of great societal importance, estuaries are complex environments increasingly subject to stress. The issue deals with their hydrodynamics, nutrient flows, and pollution patterns, as well as plant and animal life — and the constitutional issues posed by estuarine management.

SOUND IN THE SEA, Vol. 20:2, Spring 1977 — Beginning with a chronicle of man's use of ocean acoustics, this issue covers the use of acoustics in navigation, probing the ocean, penetrating the bottom, studying the behavior of whales, and in marine fisheries. In addition, there is an article on the military uses of acoustics in the era of nuclear submarines.

GENERAL ISSUE, Vol. 20:3, Summer 1977 — The controversial 200-mile limit constitutes a mini-theme in this issue, including its effect on U.S. fisheries, management plans within regional councils, and the complex boundary disputes between the U.S. and Canada. Other articles deal with the electric and magnetic sense of sharks, the effects of tritium on ocean dynamics, nitrogen fixation in salt marshes, and the discovery during a recent Galápagos Rift expedition of marine animal colonies existing on what was thought to be a barren ocean floor.

THE DEEP SEA, Vol. 21: 1, Winter 1978 — Over the last decade, scientists have become increasingly interested in the deep waters and sediments of the abyss. Articles in this issue discuss manganese nodules, the rain of particles from surface waters, sediment transport, population dynamics, mixing of sediments by organisms, deep-sea microbiology — and the possible threat to freedom of this kind of research posed by international negotiations.

MARINE MAMMALS, Vol. 21:2, Spring 1978 — Attitudes toward marine mammals are changing worldwide. This phenomenon is appraised in the issue along with articles on the bowhead whale, the sea otter's interaction with man, behavioral aspects of the tuna/porpoise problem, strandings, a radio tag for big whales, and strategies for protecting habitats.

*Since going to press, these issues have gone out of print in addition to those listed on facing page.

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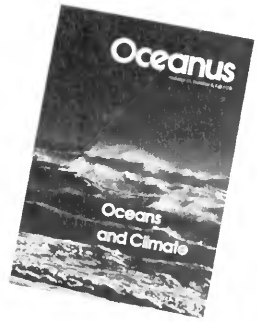

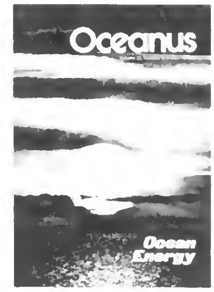

GENERAL ISSUE, Vol. 21:3, Summer 1978— The lead article looks at the future of deep-ocean drilling, which is at a critical juncture in its development. Another piece — heavily illustrated with sharp, clear micrographs — describes the role of the scanning electron microscope in marine science. Rounding out the issue are articles on helium isotopes, seagrasses, red tide and paralytic shellfish poisoning, and the green sea turtle of the Cayman Islands.

OCEANS AND CLIMATE, Vol. 21:4, Fall 1978 — This issue examines how the oceans interact with the atmosphere to affect our climate. Articles deal with the numerous problems involved in climate research, the El Niño phenomenon, past ice ages, how the ocean heat balance is determined, and the roles of carbon dioxide, ocean temperatures, and sea ice.

HARVESTING THE SEA, Vol. 22:1, Spring 1979— Although there will be two billion more mouths to feed in the year 2000, it is doubtful that the global fish harvest will increase much beyond present yields. Nevertheless, third world countries are looking to more accessible vessel and fishery technology to meet their protein needs. These topics and others — the effects of the new law of the sea regime, postharvest fish losses, long-range fisheries, and krill harvesting — are discussed in this issue. Also included are articles on aquaculture in China, the dangers of introducing exotic species into aquatic ecosystems, and cultural deterrents to eating fish.

GENERAL ISSUE, Vol. 22:2, Summer 1979 — This issue features a report by a group of eminent marine biologists on their recent deep-sea discoveries of hitherto unknown forms of life in the Galápagos Rift area. Another article discusses how scuba diving is revolutionizing the world of plankton biology. Also included are pieces on fish schooling, coastal mixing processes, chlorine in the marine environment, drugs from the sea, and Mexico's shrimp industry.

OCEAN/CONTINENT BOUNDARIES, Vol. 22:3, Fall 1979— Continental margins are no longer being studied for plate tectonics data alone, but are being analyzed in terms of oil and gas prospects. Articles deal with present hydrocarbon assessments, ancient sea-level changes that bear on petroleum formations, and a close-up of the geology of the North Atlantic, a current frontier of hydrocarbon exploration. Other topics include ophiolites, subduction zones, earthquakes, and the formation of a new ocean, the Red Sea.

OCEAN ENERGY, Vol. 22:4, Winter 1979/80 — How much new energy can the oceans supply as conventional resources diminish? The authors in this issue say a great deal, but that most options — thermal and salinity gradients, currents, wind, waves, biomass, and tides — are long-term prospects with important social ramifications.

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